2nd FLOOR

The Journal of

THE ROYAL AERONAUTICAL SOCIETY

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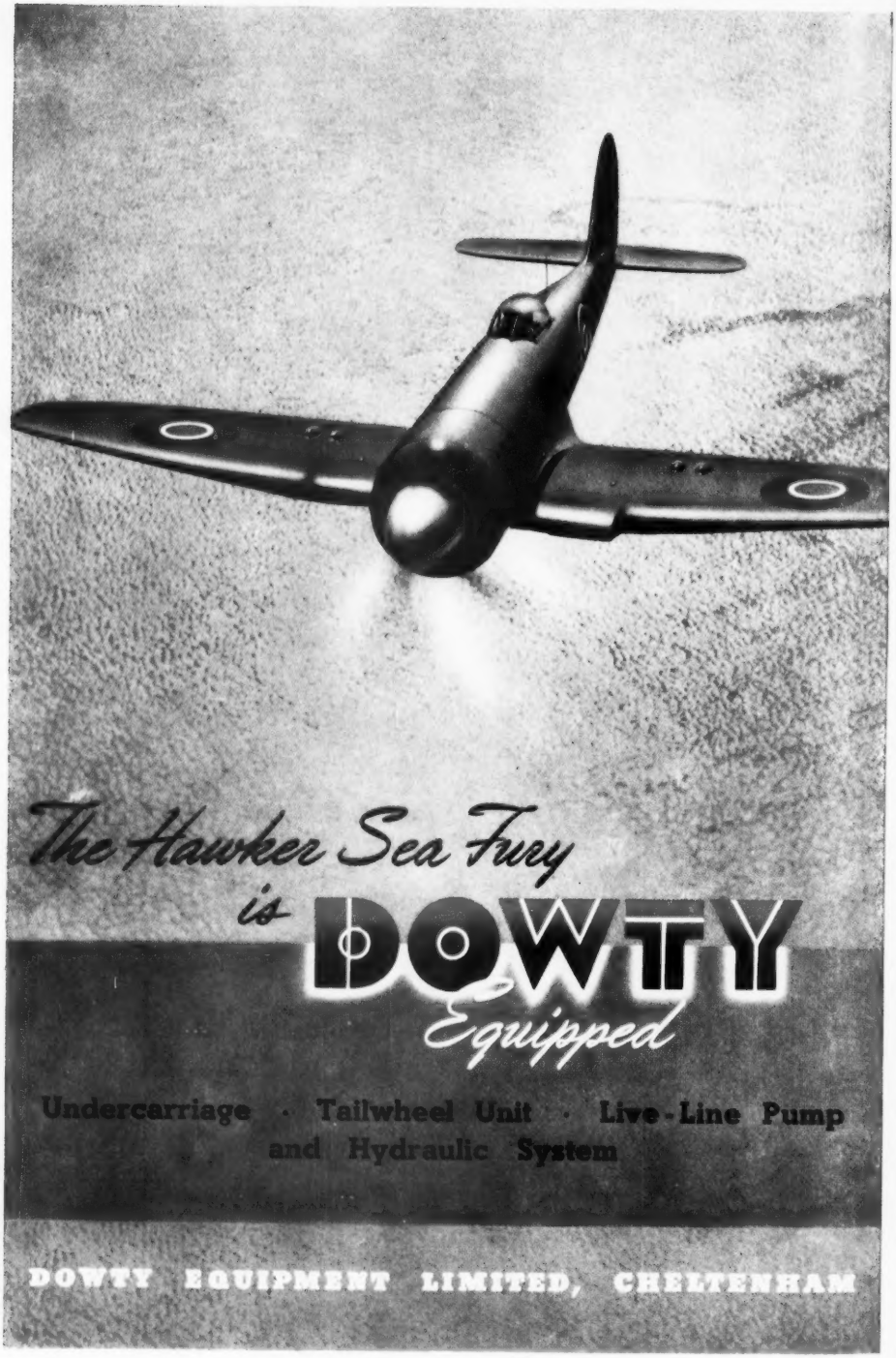
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THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1

JULY NOTICES 1948

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

AUGUST BANK HOLIDAY

The Library and Offices of the Society will be closed from 5 p.m. on Friday, 30th July until 9 a.m. on Tuesday, 3rd August 1948.

CONTENTS OF THE JULY JOURNAL

The 36th Wilbur Wright Memorial Lecture—Size in Transport, by A. Gouge, B.Sc., F.R.Ae.S.
Visual Aids to Low Visibility Conditions, by E. S. Calvert, B.Sc., A.R.C.Sc.I.
Aircraft Accidents, by R E. Hardingham, O.B.E.

BIRTHDAY HONOURS

KNIGHT BACHELOR

A. Gouge, B.Sc., M.I.Mech.E., F.I.Ae.S. (Fellow).

ORDER OF THE BATH (Military Division)

Knight Commander

Air Marshal the Hon. Sir Ralph A. Cochrane, K.B.E., C.B., A.F.C. (Associate Fellow).

ORDER OF THE BATH (Civil Division)

Companions

H. M. Garner, M.A. (Fellow)
O. Thornycroft, O.B.E., B.A., M.I.Mech.E. (Fellow).

ORDER OF THE BRITISH EMPIRE (Military Division)

Knight Commander

Acting Air Commodore F. Whittle, C.B., C.B.E., M.A., D.Sc., F.R.S. (Fellow).

ORDER OF THE BRITISH EMPIRE (Civil Division)

C.B.E.

G. R. Dawbarn, M.A., F.R.I.B.A. (Fellow).

O.B.E.

C. H. Griffiths, A.R.C.Sc. (Fellow)
W. Tye, B.Sc. (Fellow).

M.B.E.

W. H. Darlington, M.Sc., A.M.I.Mech.E. (Associate Fellow).

ANGLO-AMERICAN AERONAUTICAL CONFERENCE 1949

Arrangements are now being made by the Institute of the Aeronautical Sciences and the Society for the Anglo-American Aeronautical Conference which will be held in America in the late spring of 1949. Full details of the programme and arrangements will be published as soon as possible. Members who propose to attend should inform the Secretary.

RETIRED MEMBERS

The Council have agreed, under Rule 18 of the Society's Rules, that any member of the Society who has been a member for not less than 25 years and has retired from regular employment or occupation may continue as a member with full membership rights (other than the right to receive copies of the Journal) without further payment of annual subscription. Such members may continue to receive copies of the Journal on payment of a subscription of £1 11s. 6d. per annum.

CORRECTIONS

The notice in the June Monthly Notices about the income of the Society for 1947 should have read "the excess of expenditure over income for 1947 was £1,045 8s. 3d."

The number of the June Journal should have been 450 and not 500.

COLLEGE OF AERONAUTICS—NEW SESSION

Applications are invited by the Board of Entry, College of Aeronautics, from suitable candidates for the two-year course beginning 4th October 1948. Candidates should be of graduate standard, but the possession of a degree is not essential. In addition to the main departments, Aerodynamics, Aircraft Design and Aircraft Propulsion, a fourth department, Aircraft Production and Economics, is now being established. Full particulars may be obtained from the Registrar, College of Aeronautics, Cranfield, Bletchley, Bucks.

INTERNATIONAL CONFERENCE ON NOISE AND SOUND TRANSMISSION

A three-day International Conference on Noise and Sound Transmission is being organised by the Acoustics Group of the Physical Society on 14th, 15th and 16th July. The meetings will be held in the Jarvis Hall of the Royal Institute of British Architects, 66 Portland Place, London, W.1. Morning sessions will begin at 10 a.m. and afternoon sessions at 2.30 p.m.

Papers will be read by British, American and European authors on sound insulation in buildings, aircraft and ships; impact sound; resilient suspension systems; proposals for standardisation of measurement and the measurement of noise.

Anyone wishing to attend should notify the Joint Honorary Secretaries of the Acoustics Group, 1 Lowther Gardens, Prince Consort Road, London, S.W.7, who may also be able to supply summaries of the papers to be read.

LECTURERS AT THE COLLEGE OF AERONAUTICS

Applications are invited for the posts of Senior Lecturer in Mathematics (Department of Aerodynamics) and Senior Lecturer in Component and Detail Stressing of Aircraft Structures (Department of Aircraft Design) at the College of Aeronautics.

Salaries for both posts will be within the range of £600-£800 a year according to qualifications, plus Superannuation under the Federated Superannuation System for Universities.

Applications for Senior Lecturer in Mathematics, marked as such, and giving full details of qualifications, experience and references, should be sent to the Registrar, College of Aeronautics, Bletchley, Bucks, not later than *24th July* 1948. A wide knowledge of applied mathematics and of the closely related departments of pure mathematics is essential for this post, as well as experience in research. A knowledge of aerodynamics and of numerical mathematics would be an advantage.

Candidates for the post of Senior Lecturer in Component and Detail Stressing of Aircraft Structures should possess as many of the following qualifications as possible: (1) At least three years' experience in an aircraft stress office engaged on actual stressing of aircraft structures. (2) Experience of the full-scale testing of aircraft details and components and of the design of equipment for such testing. (3) A university degree in engineering or applied mathematics or membership of a

recognised professional institution. Practical workshop and drawing office experience would be an advantage, but is not essential.

Applications giving full details of qualifications, experience and references should be marked "Senior Lecturer in Aircraft Stressing" and sent *as soon as possible* to the Registrar, College of Aeronautics.

BRANCH NOTICES AND LECTURE PROGRAMMES

GLASGOW BRANCH

Thursday, 26th August 1948—" Lecturettes." At The Grand Hotel, Charing Cross, Glasgow.

Tuesday, 28th September 1948—A Film Evening, at 7.30 p.m., at Prestwick Airport.

Thursday, 28th October 1948—Lecture by a Branch Member, at 7.30 p.m., at The Grand Hotel, Charing Cross, Glasgow.

Tuesday, 30th November 1948—" Lecturettes," at 7.30 p.m., at Prestwick Airport.

Thursday, 23rd December 1948—Annual General Meeting, at The Grand Hotel, Charing Cross, Glasgow.

HATFIELD BRANCH

Wednesday, 14th July 1948—Selection of Aeronautical Films.
At 6.15 p.m. in the Lecture Theatre of the de Havilland Servicing School.

Wednesday, 13th October 1948—Aircraft Photography, by John Yoxall.
At 6.15 p.m. in the de Havilland Senior Staff Mess.

Wednesday, 17th November 1948—Design Problems of Large Flying Boats, by H. Knowler, F.R.Ae.S.
At 6.15 p.m. in the de Havilland Senior Staff Mess.

Wednesday, 12th January 1949—Blind Landing Technique, by J. W. F. Mercer, B.Sc., A.C.G.I.

At 6.15 p.m. in the de Havilland Senior Staff Mess.

Wednesday, 16th February 1949—The Probable Role and Influence of Aircraft in Future Warfare, by Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

At 6.15 p.m. in the de Havilland Senior Staff Mess.

Wednesday, 16th March 1949—Annual General Meeting.

WEYBRIDGE BRANCH

J. H. Sinclair, Esq., A.R.Ae.S., has been elected Secretary of the Weybridge Branch. His address is: Vickers-Armstrongs Ltd., Weybridge, Surrey.

GRADUATES' AND STUDENTS' SECTION

Saturday, 10th July 1948—Visit to the works of D. Napier & Son, Ltd.
Tuesday, 20th July 1948—Visit to the Royal Aircraft Establishment, Farnborough.

Applications from members wishing to take part in these visits should reach the Hon. Secretary, M. C. Campion, 6a Mildenhall Road, Clapton, E.5, before 1st July. The numbers will be strictly limited, and early application is advisable.

Saturday, 14th August 1948—Visit to the National Physical Laboratory, Teddington, at 10 a.m.

Saturday, 28th August 1948—Visit to the factory of Vickers-Armstrongs Ltd. (Aircraft Section), at Weybridge, at 10 a.m.

Members wishing to take part in these visits should write to the Assistant Hon. Secretary, D. A. Thurgood, 81 Bourne Avenue, Hayes, Middlesex, before 1st August. The numbers will be strictly limited, and early application is advisable.

JOURNAL BINDING

Because of increased costs, the prices of binding of Journals will be as follows:—

1947 Volume 15/-.

Previous Volumes 17/-.

Journals should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the office of the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

NEW MEMBERS

Fellows

John D. Akerman (from Associate Fellow), Handel Davies (from Associate Fellow), Guy Charles Du Merle (from Associate Fellow), Nicholas John Hoff (from Associate Fellow), Rene Lucien (from Associate Fellow), Clark Blanchard Millikan, Howard Arthur Wills (from Associate Fellow).

Associate Fellows

Ju-Yung Cheng, Frederick Clay (from Graduate), Neilson John Hancock (from Associate), Alun Raymond Howell, James Howard Johnston, James Arneil Lang, Jesse Millington Marshall, Alfred John Nicklin, Percival Edwin Quintin Shunker, Norman Fred Simmonds (from Graduate), Albert William Thomas, Geoffrey Swan Cabot Vautier (from Graduate), Robert Hendry Weir, David Williams, Rene Maurice Michel Wisner.

Associates

Richard Allen, John Stanley Booth, Clifford Claude Caple, Alan Trevor Ching, John Henry Richard Chubb, Donald Louis James Corner (from Student), Ronald Fortescue Cronin, Kenneth James Boyd Dunlop, Ernest Clement Ely, Rupert Forrester-Simms, Alan William Nisbett Garratt (from Student), Leslie Greville Hamlet, Eric Thomas Hanley, Albert Norman Hossbach, Joseph Richard Kilner, Reginald Kenneth Law, Peter Martin (from Student), Herbert Alfred Oldfield, Kenneth Arthur John Pettet (from Student), Edward Howard Ruddock, David P. Samson, Idris Reginald George Smith, Rex Frederick Stedman, Alexander Stuart Watson, Frank Wilkinson.

Graduates

Brian Bodley Collins (from Student), Roy Edward Lambeth (from Student), John Freeman Leach (from Student), Barrie Desmond Morris (from Student), John Henry Risdon (from Student), Thomas James Taylor, William Idris Thomas (from Student), Sydney Allandale Urry.

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ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks back numbers of the Journal from F. H. Henstock, Esq., A.R.Ae.S.

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

EE.c.93—Supercharging the Internal Combustion Engine. E. T. Vincent. McGraw Hill. 1948.

L.d.123—*Notices to Airmen. Nos.* 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 194, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213.

L.k.66—Médecine de l'Aviation: bases physiologiques et physio-pathologiques. J. Malmejac. Masson et Cie. 1948.

OO.122—Aeronautical Conference, London, 1947. J. L. Pritchard and J. Bradbrooke (Editors). Royal Aeronautical Society. 1948.

S.d.97—Air Power in War. Lord Tedder. Hodder and Stoughton. 1948.

*X.b.160—Imperial College of Science and Technology Calendar. Session 1947-1948. H.M.S.O.

A.R.C. Reports and Memoranda

2195—*Empirical laws for the effect of compressibility on quarter-chord moment coefficient, and for the choice of an aerofoil with small compressibility effects on centre of pressure. W. F. Hilton.*

2227—*Lift, and pitching moment measurements on an EC*1240 *tailplane elevator at high speeds with elevator cap sealed. W. F. Hilton and A. E. Knowler.*

2241—*An exact solution of the boundary-layer equations under particular conditions of porous surface suction. B. Thwaites.*

2243—*On certain types of boundary-layer flow with continuing surface suction. B. Thwaites.*

2229—*The measurement of free air temperature from aircraft. G. S. Hislop. E. Griffiths and A. R. Challoner.*

2204—*A family of streamline bodies of revolution suitable for high-speed or low-drag requirements. A. D. Young and E. Young.*

2302—*A theoretical calculation of the reduction in drag obtainable by ejector action of the exhaust gases when mixed with the cooling air-flow of a typical air-cooled engine. Fl./Lt. A. Beeton.*

2201—*Tests of high-speed flow in diffusers of rectangular cross-section. A. D. Young and G. L. Green.*

2146—*The effect of wing planform, speed and height on the design of large aircraft. P. E. Montagnon and D. M. Hallowes.*

N.A.C.A. Technical Notes

949—*Simply supported long rectangular plate under combined axial load and normal pressure. S. Levy, D. Goldenburg and G. Zibritosky.*

948—*Artificial aging of riveted joints made in alclad* 24*S-T sheet using A*175*-T,* 17*S-T and* 24*S-T rivets. A. N. Zamboky.*

947—*Studies of blade shank form and pitch distribution for constant-speed propellers. E. G. Reid.*

946—*On the general theory of thin aerofoils for non-uniform motion. E. Reissner.*

945—*Non-destructive test methods for spot welds in aluminium-alloys. R. C. McMaster, J. F. Manildi and G. C. Woolsey.*

944—*Effect of curvature on strength of axially loaded sheet-stringer panels. W. Ramberg, S. Levy and K. L. Fienup.*

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941—*An automatic electrical analyser for* 45 *degree strain-rosette data. S. S. Manson.*

1539—*Measurements of the pressure distribution on the horizontal tail surface of a typical propeller-driven pursuit airplane in flight. III. Tail loads in abrupt pull-up push-down manœuvres. Melvin Sadoff and L. A. Clousing.*

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1469—*Tensile, fatigue, and creep properties of forged aluminium alloys at temperatures up to* 800 *degrees F. L. R. Jackson, H. C. Cross and J. M. Berry.*

1506—*An application of Faulkner's surface-loading method to prediction of hinge-moment parameters for swept-back wings. A. L. Jones and Loma Sluder.*

1541—*The effect of wing bending deflection on the rolling moment due to sideslip. Powell M. Lovell.*

1538—*Analysis of accuracy of gas-filled bellows for sensing gas density. E. W. Otto.*

1542—*Effect of rotor-blade twist and planform taper on helicopter hovering performance. Alfred Gassow.*

1332—*A rapid compression machine suitable for studying short ignition delays. W. A. Leary, E. S. Taylor, F. C. Taylor and J. Jovellanos.*

1548—*The damping due to roll of triangular, trapezoidal, and related planforms in supersonic flow. A. L. Jones and A. Alksne.*

1540—*The effect of tip modification and thermal de-icing air-flow on propeller performance as determined from wind-tunnel tests. W. H. Gray and R. E. Davidson.*

1528—*Tests of a* 45 *per cent. swept-back model in the Langley gust tunnel. H. B. Pierce.*

1543—*Effect of chordwise location of maximum thickness on the supersonic wave drag of swept-back wings. Kenneth Margolis.*

1537—*Apparent effect of inlet temperature on adiabatic efficiency of centrifugal compressors. R. J. Anderson, W. K. Ritter and S. Parsons.*

1547—*Tank tests of three types of afterbodies of a flying boat model with basic hull length beam ratio of* 10.0. *C. C. Garrison and E. P. Clement.*

1517—*Wind-tunnel investigation of an NACA* 0009 *airfoil with an* 0.25- *and* 0.50- *airfoil-chord plain flaps tested independently and in combination. Leroy Spearman.*

1519—*The buckling of a column on equally spaced deflectional and rotational springs. B. Budiansky, P. Seide and R. A. Weinberger.*

1562—*Calibration of altimeters under pressure conditions simulating dives and climbs. D. P. Johnson.*

1486—*Stress distribution in a beam of orthotropic material subjected to a concentrated load. C. B. Smith and A. W. Voss.*

1549—*Effect of yaw at supersonic speeds on theoretical aerodynamic coefficients of thin pointed wings with several types of trailing edge. W. E. Moeckel.*

N.A.C.A. Technical Memoranda

1116—*Stability of plates and shells beyond the proportional limit. A. A. Ilyushin.*

1185—*Systematic investigations of the influence of the shape of the profile upon the position of the transition point. K. Busemann and A. Ulrich.*

1188—*The elasto-plastic stability of plates. A. A. Ilyushin.*

1175—*Fundamental aerodynamic investigations for development of arrow-stabilised projectiles. Hermann Kurzweg.*

1139—*Planing of watercraft. Herbert Wagner.*

1159—*Wind-tunnel measurements of the Henschel missile "Zitterrochen" in subsonic and supersonic velocities. Weber and Kehl.*
Wind-tunnel measurements on the wing of the Henschel missile "Zitterrochen" in subsonic and supersonic velocities. Kehl.

1180—*Maintaining laminar flow in the boundary layer using a swept-back wing. Brennecke.*

N.A.C.A. Technical Reports

774—*Effect of tilt of the propeller axis on the longitudinal-stability characteristics of single-engine airplanes. H. J. Goett and N. K. Delaney.*

766—*Aerodynamic and hydrodynamic tests of a family of models of flying-boat hulls derived from a streamline body NACA Model* 84 *series. J. B. Parkinson, R. E. Olsen, E. C. Draley and A. A. Luoma.*

769—*The effect of mass distribution on the lateral stability and control characteristics of an airplane as determined by tests of a model in the free-flight tunnel. J. C. Campbell and C. L. Seacond.*

803—*Wind-tunnel investigation of the effects of profile modification and tabs on the characteristics of ailerons on a low-drag airfoil. R. M. Crane and R. W. Holtzclaw.*

Australian Council for Aeronautics

ACA-34—*Stability derivatives, determination of Lp by free oscillations. J. M. Evans and R. M. Davies.*

ACA-33—*Stability derivatives, wind-tunnel interference on the lateral derivatives Lp, Lr and Lv, with particular reference to Lp. J. M. Evans.*

SM-84—*The strength of wooden box spars. J. M. Radok, J. O. Silberstein and H. A. Willis.*

SM-105—*Panel shape for least weight design of stiffened cylinders in pure bending. N. B. Joyce and L. H. Mitchell.*

A.48—*Numerical solutions for compressible flow past a cylinder. T. M. Cherry.*

College of Aeronautics

No. 14—*Note on the limits to the local mach number on an aerofoil in subsonic flow. A. D. Young.*

The following reports have also been received:—

British Intelligence Objectives Sub-Committee

F.I.A.T. Final Report, Nos. 683 and 631.

Publications Scientifiques et Techniques du Ministere de l'Air

Report No. 211.
Report No. N.T.26.

C.S.I.R. Division of Aeronautics

Report SM.110—*An investigation of convective gusts by means of sailplanes under S.E. Australian summer conditions. U. Radok.*

J. LAURENCE PRITCHARD,
Secretary.

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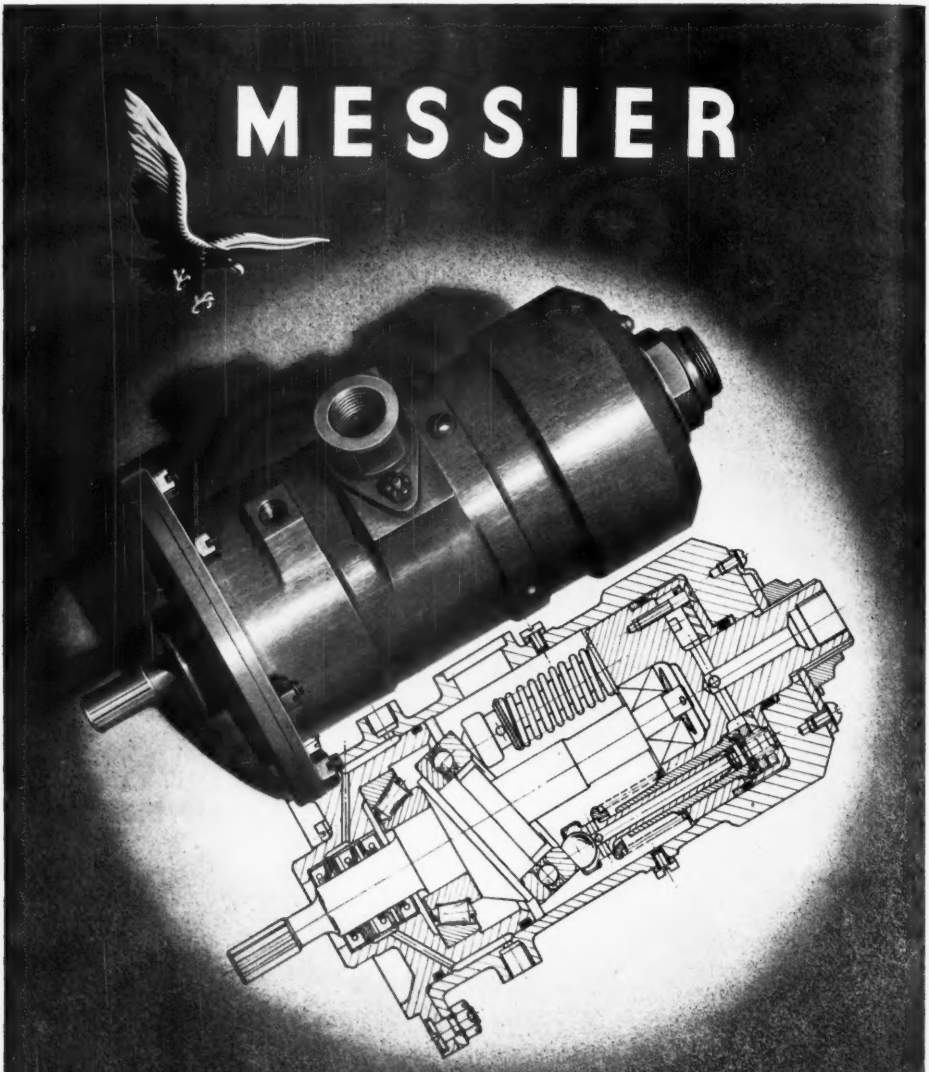

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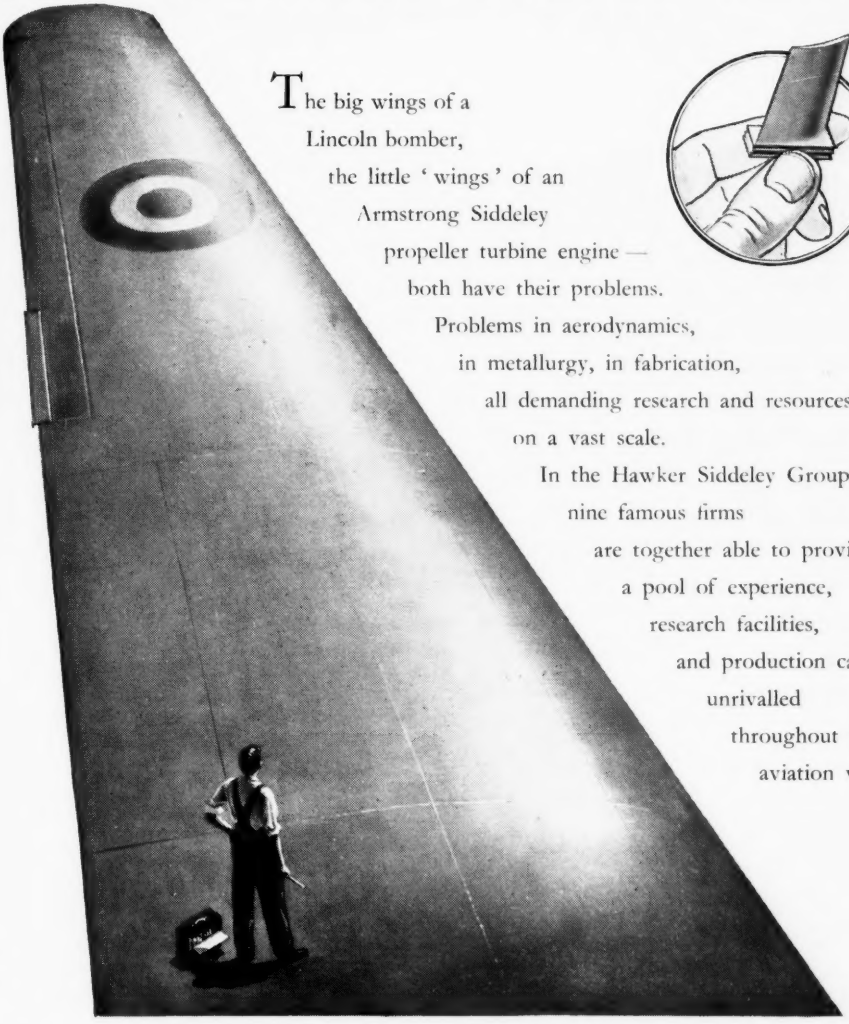
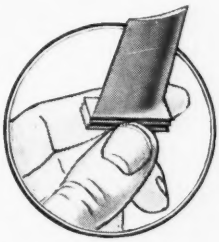
BIG WINGS AND LITTLE WINGS





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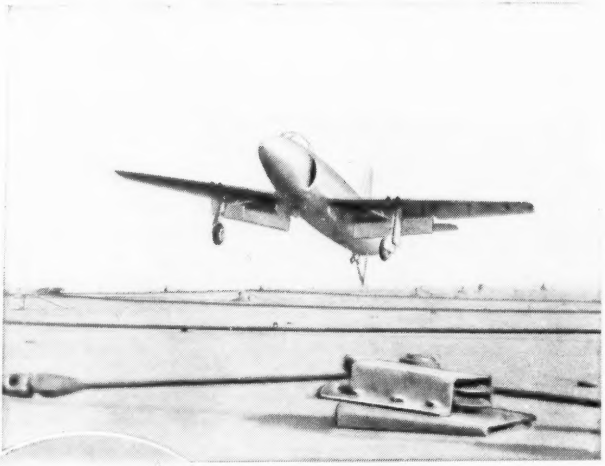

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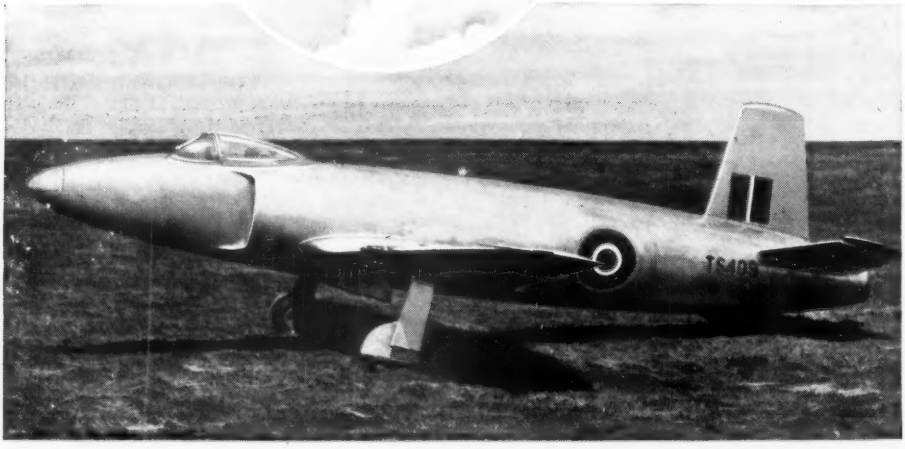

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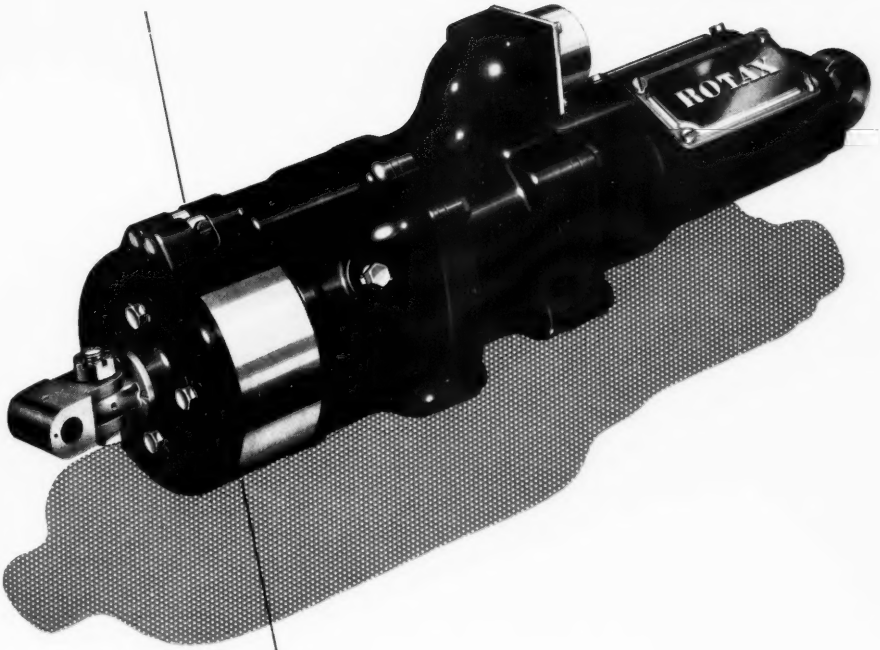

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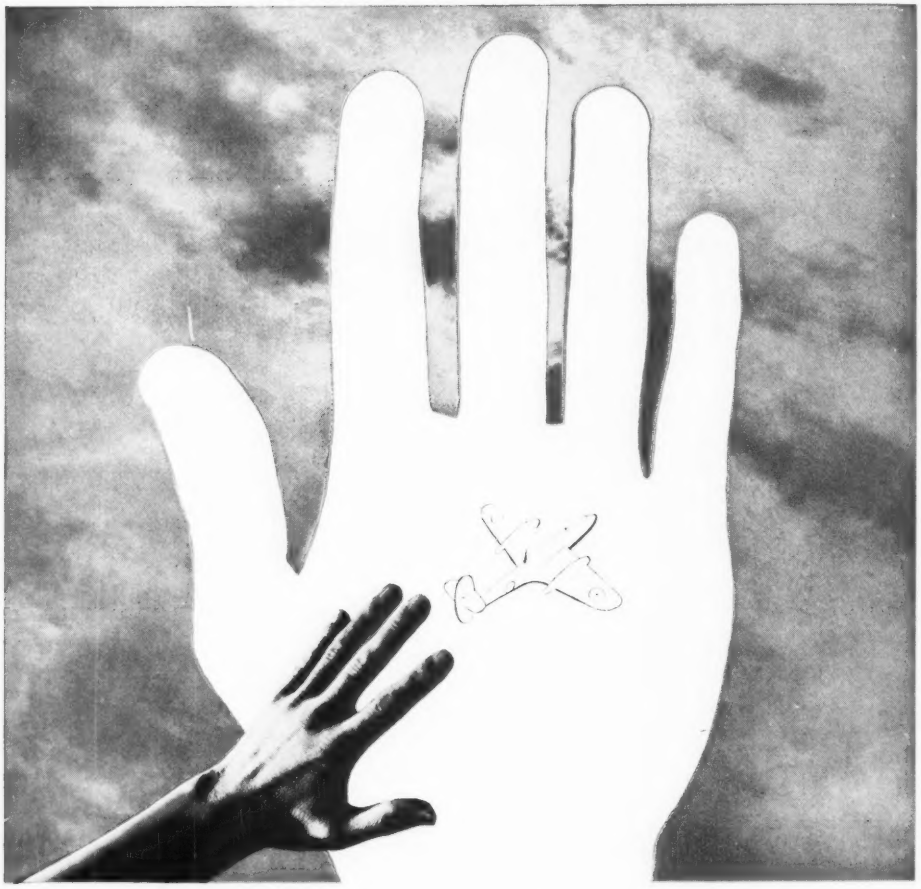

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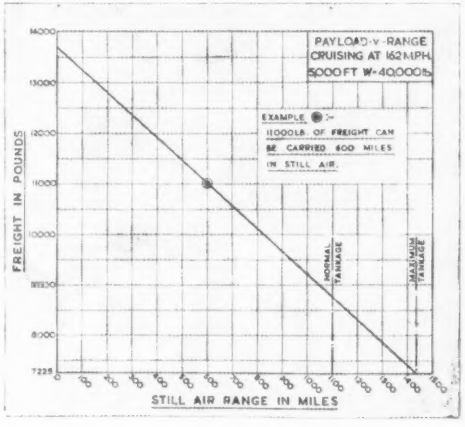

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THE 36th WILBUR WRIGHT MEMORIAL LECTURE

SIZE IN TRANSPORT

A review of the development of the subject, with particular respect to size, and the application of its lessons to Air Transport.

by

ARTHUR GOUGE, B.Sc., F.R.Ae.S.

Mr. Gouge joined Short Brothers (Rochester and Bedford Ltd.) in 1915 *and from* 1926 *until* 1943 *was responsible for the design of the many famous Short flying boats, becoming Chief Designer in* 1926, *General Manager in* 1929 *and Vice-Chairman of the Company in* 1939. *After Short Brothers Ltd. was taken over by the Government in* 1943 *he joined Saunders-Roe Ltd. as Vice-Chairman and Chief Executive of that Company.*

He was President of the Royal Aeronautical Society from 1942 *to* 1944 *and President of the Society of British Aircraft Constructors Ltd. in* 1945. *He was awarded the British Gold Medal for Aeronautics in* 1937 *and the Musick Memorial Trophy in* 1939.

THE THIRTY-SIXTH Wilbur Wright Memorial Lecture was delivered before the Society by Mr. A. Gouge on Thursday, 27th May, 1948 at 6 p.m. at the Institution of Civil Engineers, Great George Street, London, S.W.1. The chair was taken by Dr. H. Roxbee Cox, President of the Society.

The President: The main purpose of the Meeting was to hear the 36th Wilbur Wright Memorial Lecture, but before that was read he had the pleasant duty of presenting the awards which the Society had made for the year 1947.

Society's Gold Medal

The highest honour the Society could confer had been awarded to Professor Sir Bennett Melvill Jones, C.B.E., A.F.C., F.R.S., Hon.F.I.Ae.S., F.R.Ae.S., Francis Mond Professor of Aeronautical Engineering, University of Cambridge, for his outstanding work in Aerodynamics over the past thirty-eight years.

This was only the tenth occasion on which the Society's Gold Medal had been awarded.

British Gold Medal for Aeronautics

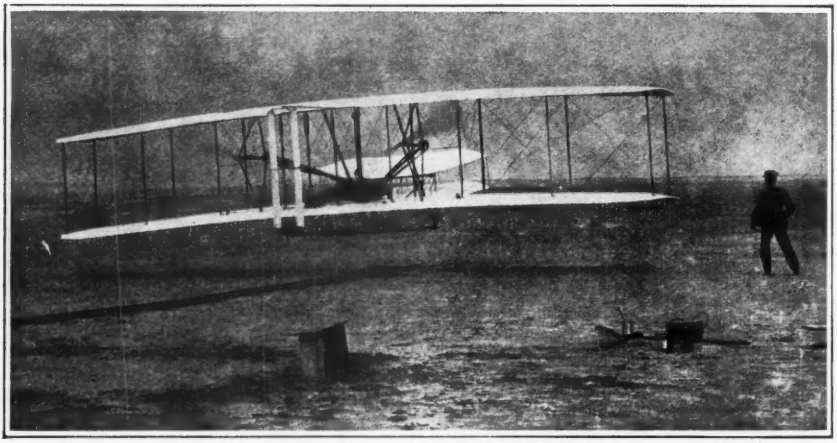
This was awarded for an outstanding achievement leading to advancement in Aeronautical Science. The advancement made during the past few years in aero-engines made it appropriate that this medal should be awarded to E. W. Hives, C.H., M.B.E., F.R.Ae.S., Managing Director, Rolls-Royce Ltd., with which firm he had been associated for forty years, for his work on aero-engine development.

Society's Silver Medal

Awarded for some advance in Aeronautical Design. One of the most striking advances recently had been in the progress of the helicopter and this Medal had been awarded to I. I. Sikorsky, Engineering Manager, Sikorsky Aircraft Division of United Aircraft Corporation, for his work on the development of the helicopter. Mr. Sikorsky was unable to be present but arrangements were being made to present the Medal in America.

British Silver Medal for Aeronautics

Awarded for an achievement leading to advancement in Aeronautical Science, it had this year been awarded posthumously to Robert Kronfeld for his gliding achievements. For over twenty years he was one of the most famous glider pilots in the world and he lost his life flying an experimental glider earlier this year. He had asked Mrs. Kronfeld to be there this evening to receive the Medal.



The first controlled and sustained flight, 17th December 1903, Orville Wright piloting the machine; Wilbur Wright on foot.

Society's Bronze Medal

This was awarded for some advance in Aeronautical Design and had been given to Miss F. B. Bradfield, O.B.E., M.A., F.R.Ae.S., Principal Scientific Officer at the Royal Aircraft Establishment, for her work on aeronautical research over the past thirty years.

Simms Gold Medal

Awarded annually for the best paper read in any year before the Society on any science allied to aeronautics, it had been awarded this year to Sir William T. Griffiths, D.Sc., F.R.I.C., F.Inst.P., F.I.M., Chairman and Managing Director of the Mond Nickel Company and Vice-President of The International Nickel Company, for his paper "The Problem of High Temperature Alloys for Gas Turbines."

George Taylor (of Australia) Gold Medal

Awarded for the most valuable paper submitted or read during the previous session, it had been awarded this year jointly to Dr. J. W. Drinkwater, B.Sc., Wh.Sc., of the Ministry of Supply, and W. G. Glendinning, B.A., A.F.R.Ae.S., of the Chemistry Department, Royal Aircraft Establishment, for their paper on "The Risk of Fire and Fire Prevention Methods."

Edward Busk Memorial Prize

This year's award for the best paper received on some subject of a technical nature connected with aeroplanes had been made to Air Marshal the Hon. Sir Ralph Cochrane, K.B.E., C.B., A.F.C., A.F.R.Ae.S., Commander-in-Chief, Flying Training Command, R.A.F., for his paper on "The Development of Air Transport During the War."

R.38 Memorial Prize

Awarded for the best paper on some subject of a technical nature in the science of aeronautics, it had been awarded this year to W. M. Widgery, F.R.Ae.S., Chief Engineer of Normalair Ltd., for his paper on "Pressurisation of Aircraft."

Branch Prize

The Prize for the best paper on an aeronautical subject read before the Branches of the Society had been given this year, jointly, to A. N. Clifton, F.R.Ae.S., Chief Technician at Vickers-Armstrongs Ltd., Supermarine Works, for his paper on "Naval Aircraft" read before the Southampton Branch, and J. A. Kirk. a Student Member of the Society and a member of the Technical Staff of Short Brothers & Harland Ltd., for his paper on "Wind Tunnels" read before the Belfast Branch.

Honorary Fellowships

He had great pleasure in announcing that the following had been awarded Honorary Fellowship of the Society:

Sir Geoffrey Taylor—Yarrow Research Professor at the University of Cambridge.

Dr. Theodore von Kármán—Professor at the California Institute of Technology, and U.S. Army Chairman of the A.A.F. Scientific Advisory Board.

Sir Alliott Verdon-Roe, O.B.E.—Fellow of the Society, President of Saunders-Roe Ltd.

Mr. H. O. Short—Fellow of the Society.

Now they came to the major event of the evening, the 36th Wilbur Wright Memorial Lecture. Wilbur Wright died prematurely in 1912, and since 1913 an unbroken series of annual lectures had been read in his memory.

This evening's commemoration differed from all its predecessors because only a few months ago Orville Wright, the brother and collaborator of Wilbur Wright had died.

Whatever memorial might be created to keep alive the memory of Orville Wright, inevitably they would remember him, the first man to fly in a heavier-than-air machine, when they held their annual memorial lecture dedicated to his brother. And whatever memorial might be erected to Orville, it too, would remind them of Wilbur. In their work these two men were as one.

The Society had suffered grievous losses in the ranks of its most eminent members in the past year, and to one of those men besides Orville Wright it was particularly appropriate to refer that evening—Griffith Brewer, the first Englishman to fly in a heavier-than-air machine and the friend and sponsor of the Wrights. He, too, had died only a few weeks after his old friend Orville Wright.

Those two passed on full of years and honour, and they would long be remembered.

This year the man who would lecture in honour of Wilbur Wright was one who was already famous. They all knew enough of aeronautical history and achievement to know the career of Arthur Gouge; he had spent a lifetime designing and building aircraft, nearly always flying boats. He could imagine no worthier occupation and, knowing Mr. Gouge he knew that there could not have been, nor could be, any worthier Wilbur Wright lecturer. He called on Mr. Gouge to read his paper.

1. INTRODUCTION.

THE WILBUR WRIGHT Memorial Lecture has now been read thirty-five times and I am very sensible of the honour the Council has paid me in asking me to read the thirty-sixth.

This year, unfortunately, Wilbur Wright's brother, Orville, passed away, as also has their great friend Mr. Griffith Brewer, who was largely responsible for the idea of these Lectures. The passing of these pioneers reminds us even more vividly of the great contribution which the Wright brothers made to modern life when they first flew on the 17th December 1903 at Kitty Hawk, North Carolina.

This evening I want to talk on the subject of size of transport vehicles and its effect on operational economy, but, before speaking directly about size as applied to aircraft, I would like to review other methods of transport which have been in existence for very many more years.

The problems encountered by other types of transport during their development are, I feel, the problems, in a modified form, which we encounter to-day when we endeavour to anticipate the needs of aircraft operating companies, always realising that different routes have different operational requirements. In spite of the variance between air transport and other means of transport, I believe that, if we can interpret history aright, it should be able to guide us—anyway, as far as broad principles are concerned — so that mistakes which may have been made by our forefathers can, as far as possible, be avoided.

With these objects in view, I want to draw your attention to a few facts in connection with transport by road, by rail and by sea, and to show how it has altered and developed over the past hundred or so years. Also, I want to point out, if I can, the effects of what may have been premature decisions on the future of a whole transport system.

Any transport system requires a considerable amount of capital, in one form or another, applied to it before it can operate at all: for instance, road transport can function only if there is a reasonable road—if none exists you are limited to travelling either on foot or on horseback.

Travel by rail can only operate if an enormous amount of capital is sunk in a track and all that goes with a track—bridges and so forth.

As far as sea transport is concerned, its limits are dictated by harbours and docks and the depth of water in the approaches.

Air transport can operate only if there is a suitable aerodrome or, in the case of aircraft which alight on water, if there is a reasonable stretch available as a landing area.

These requirements which apply to the particular form of transport need, as I have said before, a considerable amount of capital, and it is in this connection that it is important to see that the capital is spent wisely and spent with the object in view of allowing the future to develop unhindered by what is done at the time when requirements first become necessary. It is essential to take a very broad view, otherwise the particular method of transport is restricted in the future or forced along certain lines which the future may prove to be incorrect, with a consequent loss of capital and human effort.

It is my intention to-night to confine my remarks, with one or two exceptions, to those forms of transport dealing with the movement of passengers rather than goods, although I think that the arguments may apply substantially to both.

2. THE GENERAL TRANSPORT PROBLEM.

Provision of transport, like any other man-made product, depends for its existence on the laws of supply and demand, and is subject to the same consequences. It is necessary, therefore, to lay down a framework on which to base any opinions regarding this problem: at the same time, not wishing to be too technical or obscure, I intend to express it as simply as possible.

To my mind, the major factors which govern a transport system and which decide its growth (and therefore its needs) can be placed under two main headings:—

(1) The service requirements.
(2) The cost requirements.

I think that these two main considerations govern all transport, whether the journey be short or long, and these two main headings can be split down into sub-requirements. Under the heading of service requirements I would say that there are four sub-requirements:—

(1*a*) Speed.
(1*b*) Reliability.
(1*c*) Safety.
(1*d*) Frequency of departure.

(These are not necessarily in the order of priority.)

Under the heading of cost requirements we have:—

(2*a*) Capital expenditure on the means of transport itself.

(2*b*) Capital expenditure on ancillary equipment (such as tracks, docks, aerodromes).

(2*c*) General operational expenditure (wages, fuel, insurance and so on).

2.1. The Service Requirements.

I should like for a few moments to say something about the four factors of the service requirements.

(1*a*) *Speed.* A transport system of any description is founded because human beings wish to travel between two points at speeds greater than nature primarily intended. If the time taken to travel between these points is considerable, then few people will make the journey, but, if the time of operation is comparatively short, many more will do so. Therefore, it follows that if the speed of the transport vehicle is increased, the volume of traffic will also increase up to some point which will depend partly upon the population of the two centres under consideration: hence, the speed of operation is all-important in developing a transport system.

One of the first lessons to be learnt, then, is that if you employ a new system of transport which increases the speed of operation, you should plan to deal with a much bigger volume of traffic.

(1*b*) *Reliability.* It is essential if any transport system is to exist, for it to be reliable. If there are two forms of transport in which the speeds or time of journey do not differ greatly, then I think that the one which is more reliable will carry the larger volume of traffic—due regard, of course, being paid to cost and safety. Upon reliability, to a great extent, depends the punctuality of the service: nothing can be more fatal to the real success of a transport system than for the vehicle to depart late or not keep to its advertised schedule. In this connection air transport lags very much behind other forms, and it is essential, both in design and in operation, to pay great attention to the details affecting regularity. I hope to say a little more regarding this when I deal with the air transport problem.

(1*c*) *Safety.* It is extremely important that the means of transport should be safe and should not subject the passengers to any undue risk, for, while a good number of people will be prepared to take a risk, a large number will refrain from travelling on any particular service if the accident rate is high. I am of the opinion that it is impossible to place too much emphasis on the safety aspect: I think that it should be one of the very first requirements and should be studied at the beginning of the specification, either of the type of transport or its method of operation.

(1*d*) *Frequency of departure.* This controversial item is subject to widely differing opinions, and, although there is much to be said for E. P. Warner's "infinitely high frequency" which he so picturesquely described in his Wilbur Wright Lecture* as "non-stop from everywhere to anywhere at ten-minute intervals," I feel that the economic penalties of providing this will entirely preclude its realisation.

After studying schedules of all descriptions, I have come to the conclusion that frequency in general is related almost solely to the journey time. Figure 1 illustrates this point of view, and is founded on what has been extracted from the various schedules. From this chart you will see that a line drawn with a gradient of about one passes evenly through the scattered set of points, and there are cases ranging from a gradient of .75 to a gradient of 1.5 with some spots outside, usually for very definite reasons.

At first glance this may seem rather strange, but let us consider the short journey. We find that, over extremely short distances which could well be walked in a matter of minutes, a high frequency must be supplied and, in the limit, the engineer's answer to this is the escalator or moving platform.

Over distances and times of five minutes or more, omnibuses with a frequency of the same order or slightly more are satisfactory, or at least one finds that this is so in the case of present schedules.

Over train journeys of 80 miles or so, taking up the time of about 1½ hours, we find again that the frequency is of the order of an hour or so: over longer train journeys of approximately 8 hours, the frequency is about 6 or 8 hours.

When we consider seaborne traffic and go to the other end of the scale—namely, the Atlantic crossing—we find that the Cunard

* 31st Wilbur Wright Lecture. Post-War Transport Aircraft, by E. P. Warner. Journal R.Ae.S., July 1943.

Line supplies, on its highest class service, a frequency of approximately 8 days for a 5-day journey.

It is true that the London Transport system offers, in many cases, higher frequencies than we have shown, but I feel that these are conditioned by the inter-action of density of traffic and the technical limitations in the size of vehicle.

On consideration, then, we find that the result shown in the chart is not really surprising, but I should like to impress upon you that the line drawn covers all forms of transport from an omnibus taking 5 minutes to the largest liner crossing the Atlantic, and it cannot be coincidence that they all fall approximately on the same line.

Figure 2 gives the "Percentage Utilisation against Number of Vehicles Required for Different Frequencies of Service." (I have assumed the provision of service all round the clock, but similar conclusions would result if a daylight service only was considered and the percentage utilisation expressed in terms of the time concerned.)

You will note that the provision of one vehicle and 100 per cent. utilisation allows one journey at intervals of twice the single-journey time: this is, of course, a purely theoretical figure and of no practical value. If we seek to provide a period equal to the journey time, the provision of 3 machines will allow the utilisation to fall to 66 per cent.

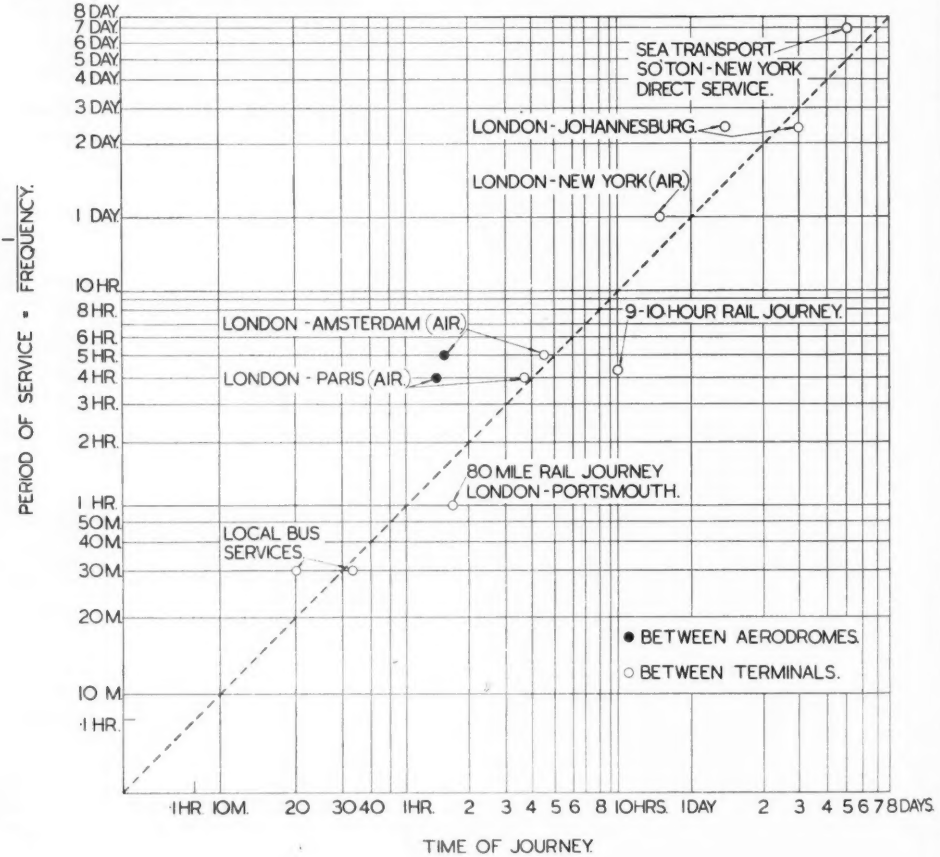


Fig. 1.

General transport problem.
Frequency of departure—journey time.

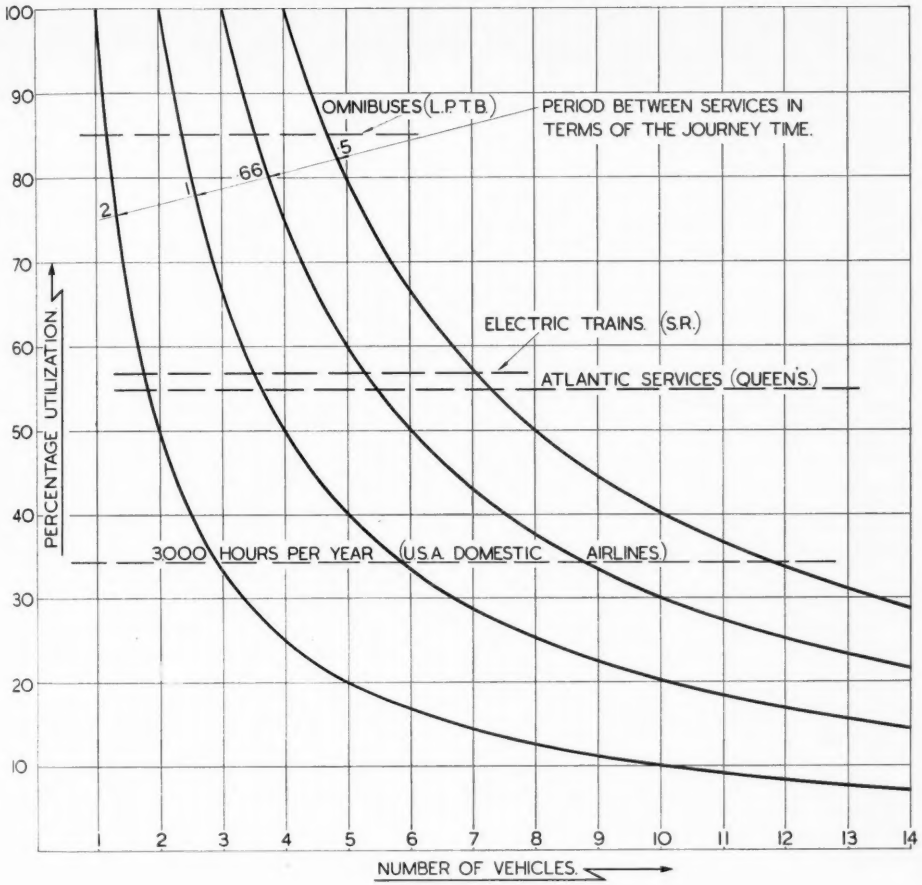


Fig. 2.

General transport problem.
Hours of utilisation—No. of vehicles for various journey times.

On the diagram I have indicated the percentage utilisation of various systems of transport. We see that the Trans-Atlantic utilisation is about 55 per cent., the London Passenger Transport omnibus utilisation is about 85 per cent, based on an 18-hour day, and the percentage utilisation on the Southern Railway suburban traffic is 58 per cent. You will also notice that the utilisation on U.S.A. domestic airlines is 34 per cent.

It seems to me that there is much to be said on the subject of the correct frequency to be provided in the case of air transport, and this might well furnish enough material for a paper on its own: however, from what I have said before, you will appreciate that I think that frequency in this form of transport will settle down and fall not far from the line shown in Fig. 1.

In conclusion, it would appear that the speed of the vehicle dictates the frequency, and the density of traffic dictates the size of vehicle, unless the latter is restricted by other considerations.

2.2. The Cost Requirements.

Referring for a moment to the cost requirements, it is essential in the long run, in any form of transport, that the receipts should be in excess of the over-all expenditure. How-

ever, it is as well not to look at this from too narrow a viewpoint, because an increased volume of traffic will have the effect, in general, of reducing cost of operation, and therefore should reduce the charges, which again will increase the traffic, in much the same way as indicated under speed of operation.

(2*a*) *Capital expenditure on the means of transport.* There is little doubt that in each case the interest on this outlay is reasonably small compared with the other items involved.

(2*b*) *Capital expenditure on ancillary equipment.* This item is an extremely interesting one, because it does vary a great deal with the different forms of transport. It is a difficult task to assess the capital expenditure that has been used over the past century or so on roads, bridges, railway tracks, stations, docking systems, etc., but it is a very necessary part of a transport system—in fact, it is so large in some cases that it actually defines the vehicle.

(2*c*) *General operational expenditure.* This is probably the largest part of any transport system, and includes wages of operational personnel, fuel, insurance, depreciation, operation of ground aids and maintenance of ancillaries, and so on. It can be markedly influenced by the amount spent on the equipment itself—higher-quality machines in the first instance should not require so much expenditure to operate them. It is again influenced if it becomes necessary to operate smaller units than the volume of traffic demands.

3. SURVEY OF GROUND TRANSPORT SYSTEMS.

Having briefly reviewed the variables which are involved in the transport problem, I should like to make the point that the size of any vehicle is determined by the density of the traffic or by the capacity of the ancillaries by which it is handled.

I think it is true to say that the transport unit will naturally tend to reach the largest technically possible for the route under consideration, and I hope to bring this out with greater force later.

After a certain ratio of the value of the ancillaries to the value of the transport unit is reached, it is economically impossible to alter the ancillaries to meet an increase in traffic demand—in other words, the weight of capital sunk in the ancillaries will tend to lead the mode of operation of the transport system along lines which may be obsolete in a very few years. The operators are then faced with either sacrificing a great deal of capital expenditure or running an out-of-date system. This may be possible internally in one country, but it could not last for long in international competition.

It is of interest now, after these general remarks, to enquire how the various well-known forms of transport have met the problem as we have laid it down. I would like to review briefly the history of the three basic ground systems over the past hundred years.

Before discussing the aircraft side of my subject, I should like to cover briefly the histories of other forms of transport.

Starting with road transport, we find that, as I said before, the first requirement is a road. Roads as we know them to-day did not appear until the end of the 18th century, when Telford and MacAdam began their work.

(Before this, in 1763, the stage coach journey from London to Edinburgh took 14 days, and the capacity of the coach was probably about six. Some idea of what it looked like can be obtained from the illustration (Fig. 3), which is a reproduction of Hogarth's picture called "The Inn Yard," engraved in 1747.)

These roads were about the same as our secondary ones, and with their advent development of the stage coach proceeded rapidly.

Figure 4 shows a succession of early omnibuses. Shillibeer's omnibus operated in London in 1829, and was the first recorded vehicle intended for the general short-distance traveller. In 1832 a new Act of Parliament permitted stage coaches of all kinds to take up and set down passengers anywhere within the five-mile radius, and the 12-seater inside omnibus became the standard type.

After a time the density of traffic grew, and some passengers were accommodated on top of the coach. (The Enterprise Steam Bus was introduced in 1833, but it was before its time and restrictive legislation drove it off the road.)

Traffic congestion was occasionally felt in such places as Ludgate Circus as early as 1850.

The Exhibition of 1851 affected the London omnibus, and owners wanted to increase their accommodation per vehicle. The second sketch shows the new design then introduced, which was known as the *Knifeboard*. About

Advertiſements.
WIndſor Stage-Coach cometh every day in the week from thence by ſeven of the Clock in the Morning, to the Red Lion in Fleetſtreet, and returneth from thence towards Windſor again, at Twelve a Clock the ſame day Beginning April 26. and continuing until Michaelmas next.
If God permit.

Fig. 3.

this time there were approximately 800 London omnibuses. In 1858 the London General Omnibus Company was formed. In spite of attempts to improve the design of omnibus, the *Knifeboard* type persisted until the '80s.

The third sketch shows the standard 26-seater horse omnibus of about 1890.

In 1901 there were about 3,700 omnibuses, and 460 million passengers were carried. In the same year approximately 1,400 horse and 200 mechanical trams, with 149 miles of route, carried 340 million passengers, giving a total for the year of 800 million passengers. This represents about a quarter of the present-day road traffic.

In the early 20th century tram routes became extended, the Underground was electrified and the motor omnibus made its appearance. It was on the 14th August 1896 that Parliament sanctioned the removal of the man with the red flags and cleared the road for the development of motor traffic.

The first ten years of the 20th century was a highly experimental time as far as road transport was concerned. Steam-driven and petrol-driven vehicles were introduced together and developed in parallel.

Out of the experiments and competition of the first decade of this century emerged the London General Omnibus Company's "B" type omnibus of 1910. This was a 34-seater of 30 h.p., and it became the mainstay of the General fleet for many years. This is shown in Fig. 5.

The War of 1914-18 held up omnibus development, but progress was rapid imme-

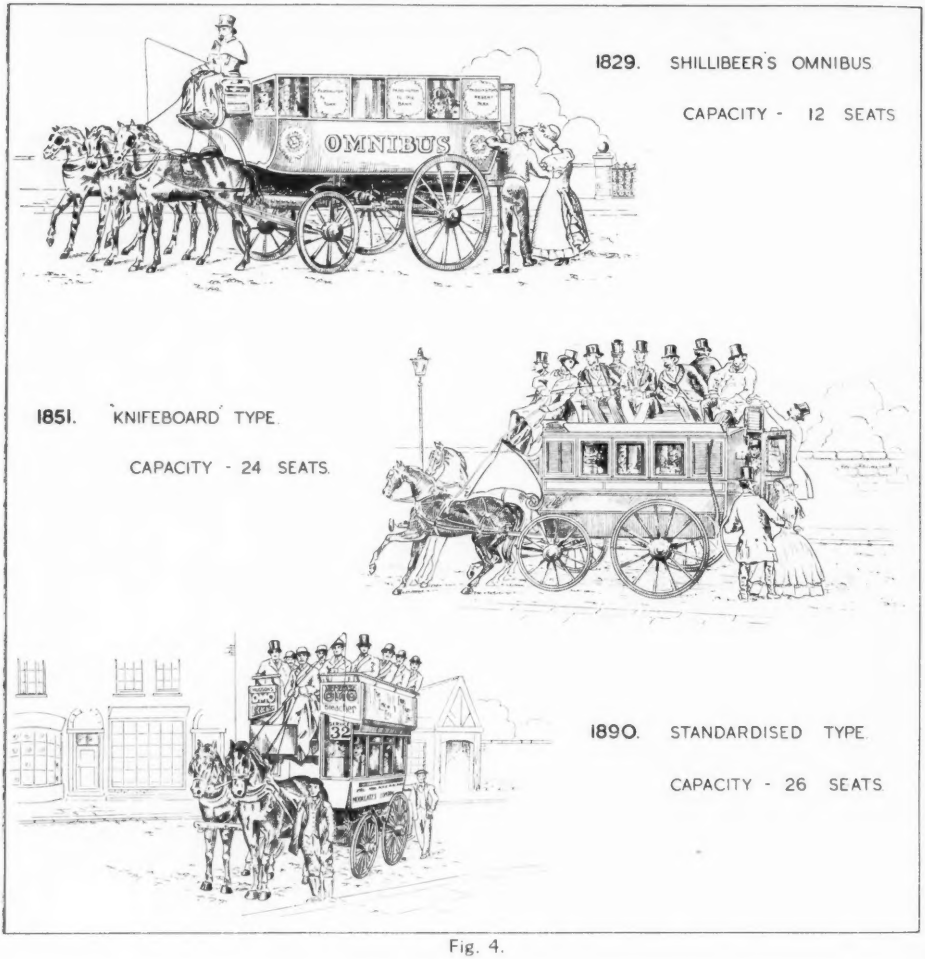


Fig. 4.

diately afterwards. The "K" type, a 46-seater, came out in 1919, and the "S" type, a 54-seater, followed in 1920; in 1925 the "NS" type subsequently became the first closed-in upper-deck omnibus. About 1925 pneumatic tyres were introduced.

The London Passenger Transport Board was formed by Act of Parliament in 1933; the total omnibuses then running were 6,000, with a route mileage of 2,400. In addition, there were 2,600 trams and 60 trolley buses. About 9½ million people were served in an area of 2,000 square miles. The present fleet of omnibuses is about 7,000.

Consequently, we can see that by 1925 the most economical size of short-distance omnibus had been reached—this was a 56-seater, although larger sizes (60-seaters) were used as long ago as twenty years. The collection of fares by one conductor made it uneconomical to go larger than a 56-seater.

It is interesting to note that legislation prohibits the use in this country of articulated vehicles for passenger transport purposes. However, in some countries this is not so—Leyland's have constructed articulated vehicles for Holland, Sweden and Denmark, and these are about 100-seaters or more. The reason why these can be used is that they

Fig. 5.

operate under a system of zone fares, and this obviates the fare-collecting difficulty.

We have a case in Swansea where a 106-seater tramway system operates, and in peak periods as many as three conductors are used.

Summarising briefly, we see that, when the omnibus was used for the job for which it was most suited, it reached its optimum size about 25 years ago. Since then progress has not been so obvious as far as the passenger has been concerned, although the technical advances have been great. My point is that, if it were not for practical limitations of operation, the capacity of these road transport units might well be doubled.

Turning now to the history of our railway system, it is interesting to remark that it has this in common with air transport—that is, it is a comparatively recent invention: road and sea transport have existed from time immemorial.

Railways were first employed in 1803 for the conveyance of coal in privately owned collieries, as an alternative to horse-drawn tramways. The Stockton and Darlington Public Railway Company was not formed until about 1818. The Bill permitting its operation was twice rejected before being

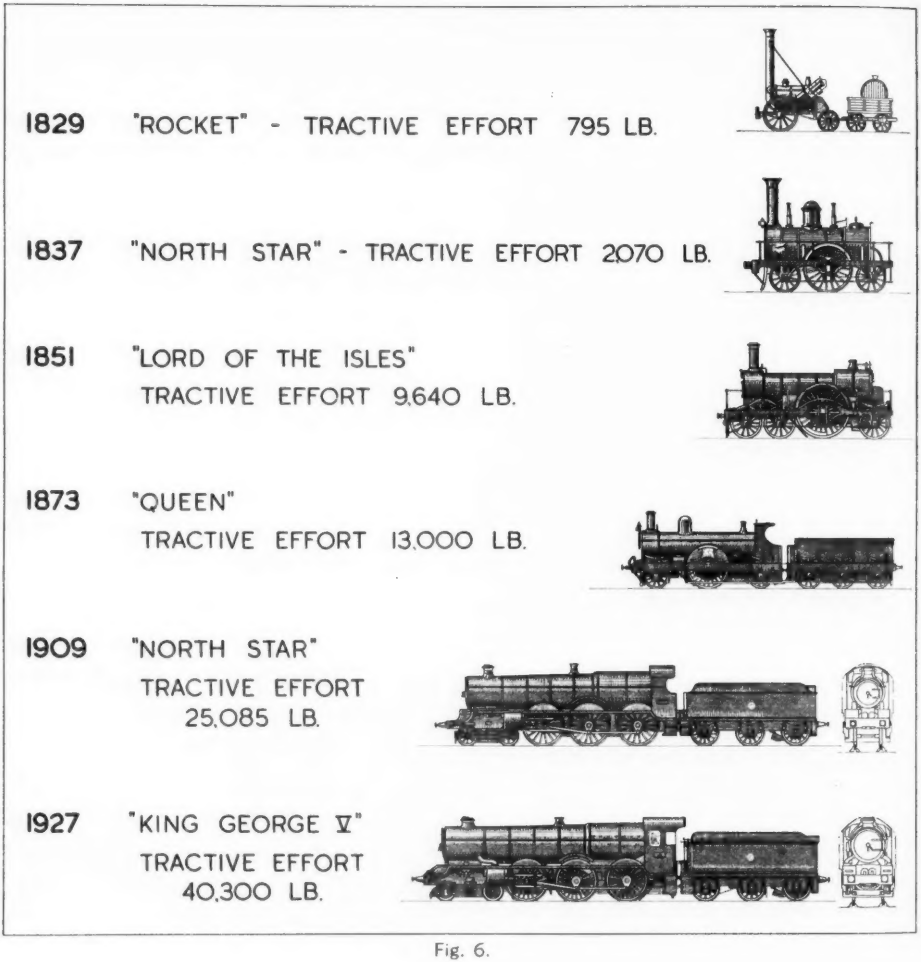


Fig. 6.

passed finally in 1821, and it was in September 1825 that the first public railway in the world was opened between Stockton and Darlington. It was not long before other companies were formed.

Although locomotives were used for the first four years on these early railway lines, directors and engineers were still in doubt as to the best method of achieving their object of passenger traction, and had not given up the idea of rope and rack methods. In 1829 the Stockton and Darlington Railway offered a £500 prize for the best method produced for achieving this: Stevenson produced his *Rocket* and won the prize, which may be said to have settled for ever this primary question on the subject. It is probably for this reason that credit is given to him as being the inventor of the first railway engine. (Actually, the *Rocket* was No. 7 on Stevenson's list of engines manufactured.)

The early history, and indeed the whole history of rail transport, is extremely wide and interesting, so we must not lose sight of our main object—namely, to trace the growth of size in this subject. To do this I have selected the locomotives mainly of one Company, and have chosen as representative those of the famous Great Western Railway, which began operating in 1837. Although

this Company originally employed a 7 ft. track instead of the 4 ft. 8½ in. of the majority of the other Companies then operating, I do not think that this will affect the issue.

Figure 6 shows in a striking pictorial way the growth of these locomotives. The first is the famous *Rocket* of Stevenson's, followed by the first Great Western locomotive, the *North Star*, also built by Stevenson, then the *Lord of the Isles*, and in 1873 the *Queen*. In 1909 we have another *North Star*, and in 1927 the famous *King George V*.

Figure 7 shows the growth of size graphically, and I have chosen the "Tractive Effort" as being indicative of locomotive size. Also given in this illustration is the growth of locomotive weight.

The *King George V* is to date the largest locomotive built by the Great Western Company. I think that I am correct in stating that it provides adequate traction for the weight and lengths of trains and the gradients of track at present possible on the Great Western Railway. I do not consider that railway engineers would have any trouble to produce a locomotive of twice or more the tractive effort of the *King* Class, but I consider that it could not be exploited fully, as the trains themselves are limited by track and platform considerations, and this Class is adequate to deal with the present situation.

Figure 8 gives information which I think is significant, namely, the growth of speed achieved in rail passenger transport. You

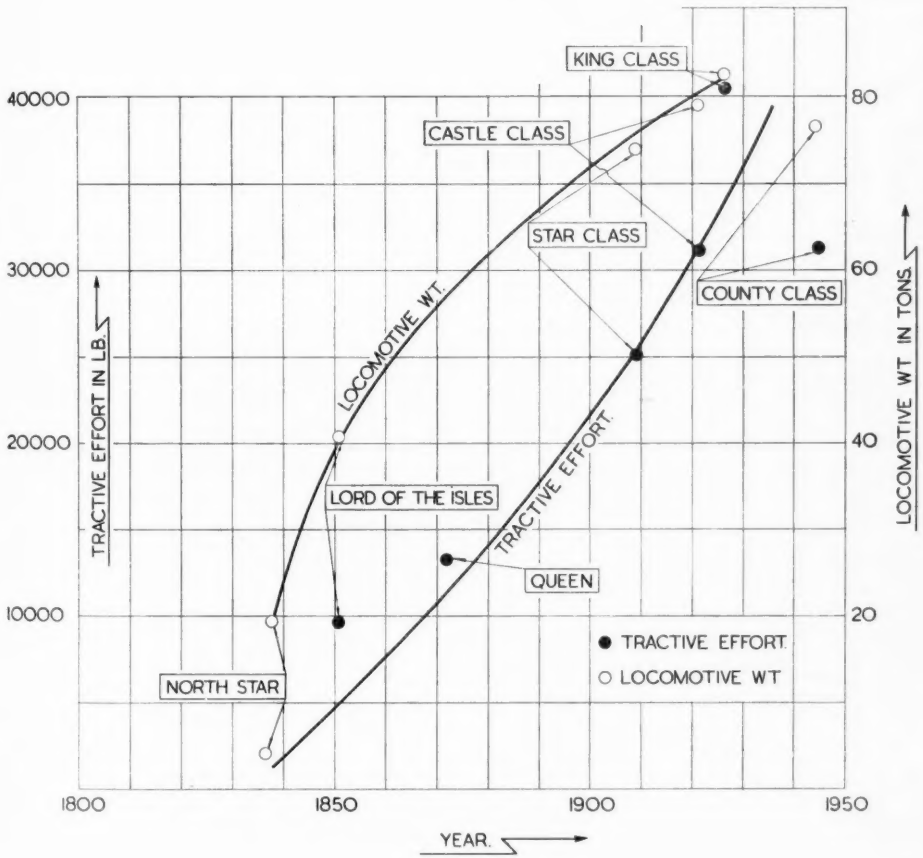


Fig. 7.
Rail transport.
Growth of tractive effort and locomotive weight.

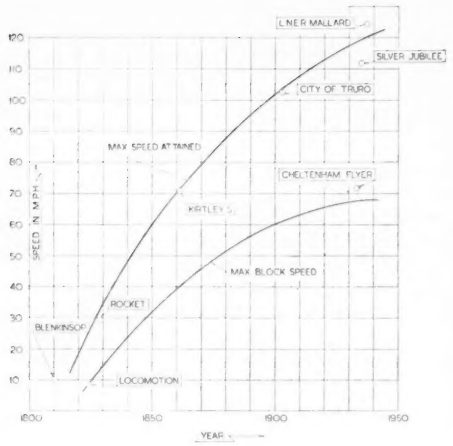


Fig. 8.
Rail transport.
Growth of speed.

will note that the block speeds have improved over the past fifty years by a matter of merely eight or nine miles per hour, and the general slope of the curve indicates quite definitely that an upper limit is being reached as far as speed on the present track is concerned.

In my opinion, this does not mean that rail traffic, particularly passenger traffic, will not be carried at greater speeds, but what it does indicate is that consideration will be given in the very near future to different forms of track, which will enable rail passenger transport to increase its speed very much beyond present-day achievements. From an engineering point of view, I can see no reason at all why rail passenger traffic should not at least double its speed—in fact, it must do so if it is to live in company with air transport over comparatively short distances.

Figure 9 shows that if ground transport increased its speed to, say, 120 miles an hour, then it would be impossible for aircraft to compete if the distance travelled was less than 150 miles. It seems astounding to me that, with cities as close together as Philadelphia and New York, it has been possible to develop air transport to the pitch it has attained (indicated in Mr. Warner's Wilbur Wright Lecture), and I would suggest that this traffic is quite likely to be temporary if the railway engineers are allowed to use their ability and ingenuity to develop a fast-moving ground service. These remarks, of course, can only apply where there is no great geographical difficulty to overcome.

The point I am making here is that air traffic will develop between Paris and London because of the English Channel and the fact that ground transport is lagging behind in development.

So far I have dealt with the "long haul" side of the rail problem, and would like to remark on local suburban traffic. The Southern Region of the British Railways affords an extremely interesting example. One of the main termini, Waterloo, handles 1,200 trains daily, and 200,000 people arrive and depart each day; these are not evenly spread over this period—for instance, in the peak hour from 8 to 9 a.m. 30,000 people arrive at Waterloo.

Suburban trains are limited in length because of platform considerations, and consequently, in order to handle the traffic, the frequency must be increased. The frequency, however, is associated with speeds of operation, braking distances and signalling facilities, and at the present moment cannot be increased beyond one every two minutes. It is interesting to remark that the North Kent Line is now beyond the saturation point, where it just cannot handle the required traffic.

Another point of interest in connection with this suburban traffic is the effect of electrification. This has been to increase the speed of operation, and it has been the practice of the Southern Railway to double their

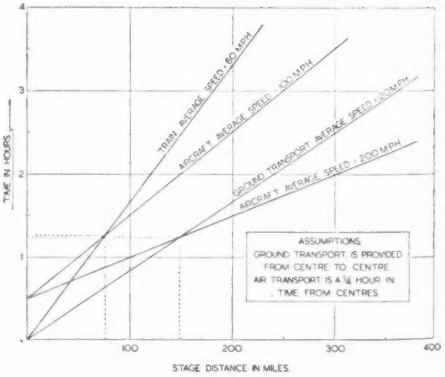

TRAIN AVERAGE SPEED 60 MPH
AIRCRAFT AVERAGE SPEED - 120 MPH
GROUND TRANSPORT AVERAGE SPEED - 120 MPH
AIRCRAFT AVERAGE SPEED - 200 MPH
ASSUMPTIONS
GROUND TRANSPORT IS PROVIDED FROM CENTRE TO CENTRE
AIR TRANSPORT IS A ¼ HOUR IN TIME FROM CENTRES
TIME IN HOURS
STAGE DISTANCE IN MILES
100
200
300
400

Fig. 9.
The general transport problem.
Time to travel by ground and air transport compared with distance.

schedule. This seems to be roughly in agreement with our hypothesis made in the General Transport Problem. The provision of this service has led to the development of suburbs, and has created without any doubt the vast local traffic now handled by the Southern Railway.

I cannot conclude by remarks on rail transport without a few words on the size of track. I do not intend to discuss in any detail the decision made many years ago, when the size of track was standardised at 4 ft. 8½ in. I would, however, point out that the effect of this decision, coupled with the height of bridges, was to almost preclude the possibility of using a double-deck railway coach, which would have been able to carry almost double the payload at no great increase in either structure weight or cost. The narrow gauge limited the size of vehicle, and, therefore, in order to carry the loads which became available, the frequency of service had to be increased, in many cases, to the point where the track is overloaded.

Speaking now for a few moments on sea transport, we have a very different story to tell and a very different picture to draw, because this form of transport is not nearly so restricted by ancillary considerations as are the others.

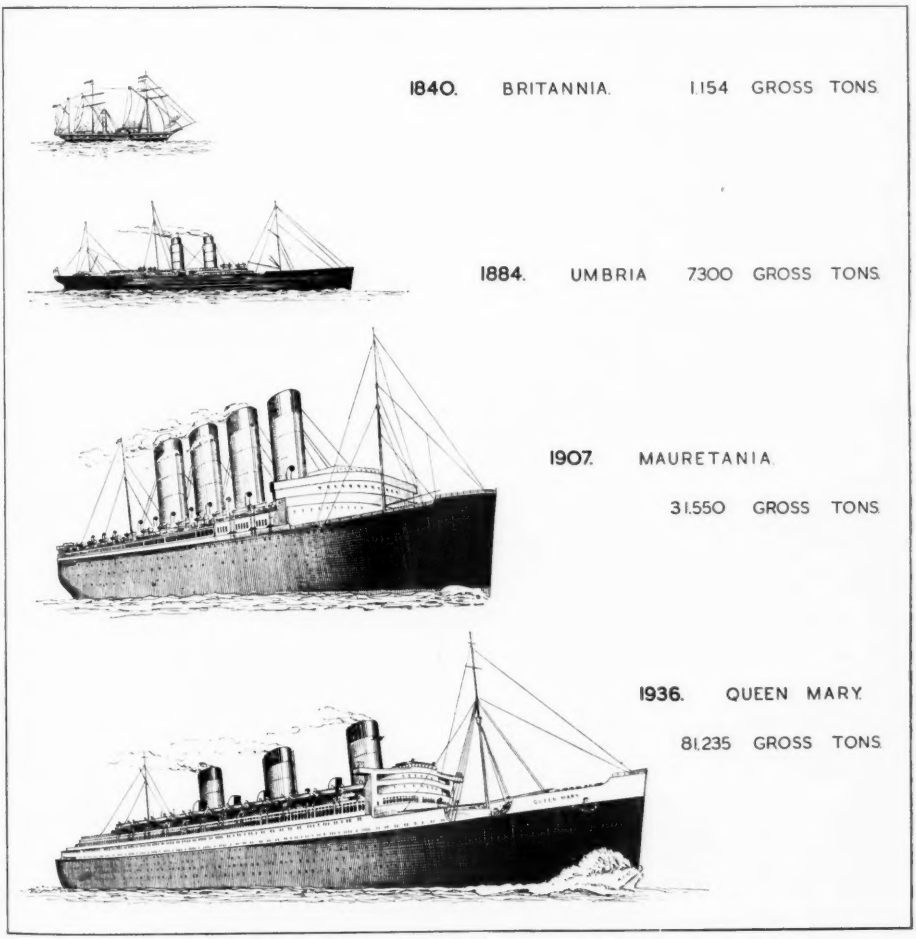


Fig. 10.

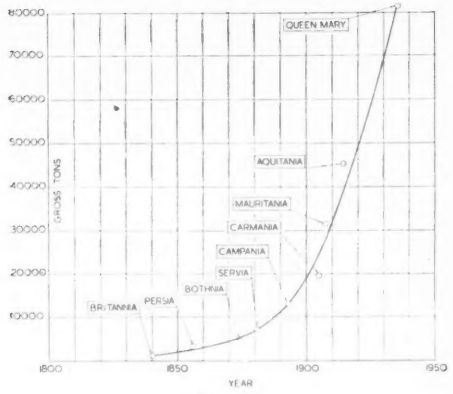


Fig. 11.
Sea transport.
Growth of gross tonnage in year.

By the early 19th century the steamship was more or less firmly established as a means of travel. However, because of the advent at this time of the famous Clipper ships (which originated from Baltimore), it was some time before the steamship was accepted completely for ocean travel. (In fact, in those days the range of steamships was restricted by the weight of fuel carried, in much the same way as our present aircraft, and it was not until the use of higher steam pressures and double and triple-expansion engines that this ceased to be a primary consideration.)

In the 1820's and the 1830's steamships crossed the Atlantic mainly under sail.

The history of steam navigation is extremely interesting and involved during this period, so, in order to simplify my point of the natural increase of sea-borne tonnage, it is better to consider the growth of size of ships used by a particular Company operating a particular route. I have chosen, perhaps naturally, the highly successful Cunard White Star Line, operating their Atlantic Mail Service.

The Cunard Line began operating in 1840 with four vessels, the *Britannia*, the *Caledonia*, the *Acadia*, and the *Columbia*, all ships of 1,154 gross tons. To-day this Company is operating the *Queen Mary* and the *Queen Elizabeth*, both vessels of over 80,000 gross tons.

Figure 10 shows in a pictorial way the growth of Atlantic Mail ships of the Cunard Line from 1840 until the present day. These ships are drawn to approximately the same scale, and you will note that over a period of one hundred years the percentage growth in gross weight is 70 to one. This brings out the remarkable growth of size of a form of transport which has not been shackled by costly ancillary equipment, and which deals with a large volume of traffic over a considerable distance.

Figure 11 shows the information given in the previous figure in a different form, and emphasises just as clearly the growth in tonnage of these North Atlantic ships. It is fairly obvious that this rate of increase cannot continue, and this leads one to think that another form of transport is about to come in and start a new era.

Figure 12 (a diagram which I have used in a previous lecture) is of great interest. This gives the time taken to cross the Atlantic from 1760 up to the present time. The first break in this curve corresponds to the change-over from sailing ships to steamships: the next break shows a change-over from steamships to aircraft. The latter coincides with the steepness of the growth of tonnage curve and the flatness in the speed curve, and leads me to believe that the change-over to which I have referred is going to take place in the near future in no uncertain fashion.

It is admitted that only the largest of the Atlantic Mail ships of their time have been taken and that there have been subsequent drops in the sizes used, but I think that these have been due to variations in world economic conditions, as well as other things. We may recall the case of the *Queen Mary*, whose keel was laid down in 1930. Owing to the serious world economic situation, work on her was suspended in December 1931, when the hull was in an advanced state of construction. With the return of an improvement in world conditions and following the amalgamation of the Cunard and White Star Lines (which the Government regarded as a necessary preliminary before granting financial assistance towards her construction), a satisfactory arrangement was finally entered into and work on her was resumed in April 1934. She was named and launched by H.M. Queen Mary on the 26th September 1934.

It is likely that the size of the two *Queens* is about the optimum that can be handled with the existing docking facilities.

If we consider other Lines than the Atlantic Mail service, we find the same story—for instance, the Suez Canal is the controlling

factor on the Australian and Far East routes, and consequently much smaller ships than the *Queen Mary* and *Queen Elizabeth* are necessary. Another good example is shown on the New York—Bermuda service, where the size of ship has steadily increased to the maximum that can be operated. The controlling factor is the depth of the " Two Rock " channel into Hamilton Harbour, which puts an absolute limit on draught. The *Queen of Bermuda* and the *Monarch of Bermuda* were specially designed to give the maximum size and capacity subject to limiting draught, and these ships were highly successful and economical.

4. SURVEY OF AIR TRANSPORT SYSTEMS.

Having briefly reviewed the historical development of other methods of transport, I should like now to consider some relevant parts of the history of air transport, chiefly with respect to size.

British commercial aviation began on the 25th August 1919, when Mr. E. Lawford, in an Airco 4a, inaugurated the first regular British airline between London and Paris. Several airlines operated independently until 1924, these being:—

1. Handley Page Air Lines Ltd.: London-Paris.
2. Instone Air Lines: Brussels-Cologne.
3. Daimler Airways: Manchester-Amsterdam.
4. British Marine Navigation: Le Havre-Channel Isles.

In 1924 Imperial Airways Ltd., a State-aided monopoly organisation, was formed, and this embraced all existing British air transport companies.

It was also about 1919 and 1920 that other countries started their air transport services. K.L.M. was formed in 1919, and the first commercial services in America began about the same time. At first the machines used were able to fly only an average of 300 hours a year, the rest of the time being occupied with maintenance work.

In order to crystalise the development, I intend, as in the preceding sections, to consider the aircraft used by a particular organisation, and I have chosen Imperial Airways. To simplify the problem further, I have selected aircraft used mainly on their London-Paris route.

Imperial Airways started operating this route daily on the 26th April 1924, and the succession of aircraft used is given in Fig. 13. Briefly, these are as follows:—

At the end of 1924 the W8f class was introduced, this was the first of the three-engined air liners, produced by Handley Page.

In July 1926 the *Argosy* class of three-engined aircraft was commissioned for the London-Paris route.

In June 1931 the first of the famous *Hannibal-Hercules* class appeared.

In September 1932 the first of the Armstrong-Whitworth *Atlanta* class was commissioned.

In 1934 the first of the four-engined *Diana* class came out.

In October 1938 the first *Ensign* operated the route.

The above machines indicate a steady growth in size. The War, however, intervened, and I thought that it would be unfair to include the aircraft which have since been used temporarily.

In parallel with these aircraft, it is interesting to trace the growth of size of flying boats used by Imperial Airways. Fig. 14 shows pictorially this line of machines.

In 1924 the *Sea Eagle* was used on the Southampton-Guernsey route.

In 1928 the first *Calcutta* made its appearance.

In 1931 the *Scipio* class was introduced. (This was originally designated the *Kent* class.)

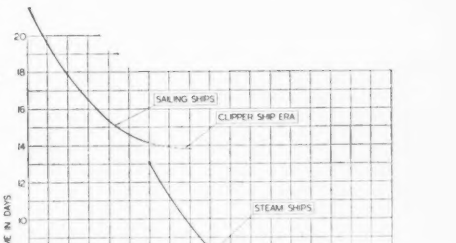


Fig. 12.
Sea transport.
Time to cross Atlantic in days-year.

In December 1936 the first of the Empire boats, the *Caledonia* was commissioned.

In September 1938 the *Champion* was flown on service.

In July 1939 the first trials of the *Golden Hind* took place. This machine was intended for the North Atlantic route.

The outbreak of hostilities with Germany on the 3rd September 1939 suspended civil air operations. However, to complete the picture, I have added the *Shetland* and the *S.R./45* to the illustration.

Finally, I have reproduced in part a diagram from the 1941 Wilbur Wright Lecture of our American friend, J. T. Trippe*. This is given in Fig. 15, and shows the successive development of marine air transports sponsored by Pan-American Airways. I have added to this the Hughes flying boat.

* 29th Wilbur Wright Lecture. Ocean Air Transport, by Juan Trippe. Journal R.Ae.S., September 1941.

In Fig. 16 I have shown the development of size of both these series of flying boats in graphical form.

Having touched on the history of landplanes and flying boats, I feel that I should mention the subject of airships.

The story of the airship goes back much farther than that of the aeroplane—in fact, it goes back to that day in 1783 when the Montgolfier brothers gave the first exhibition of their experiments at Annonay.

In 1852 Gifford showed in Paris, probably for the first time, that a "lighter-than-air" craft could be propelled and controlled.

In 1900 the first Zeppelin appeared.

In 1910 the German Airship Transportation Company known as "Delag," was formed, and before 1914 its five airships had carried 35,228 passengers and flown 107,180 miles without a single injury to passengers or crew. Nearly 100 Zeppelins were built during the War of 1914-18, but the Armistice

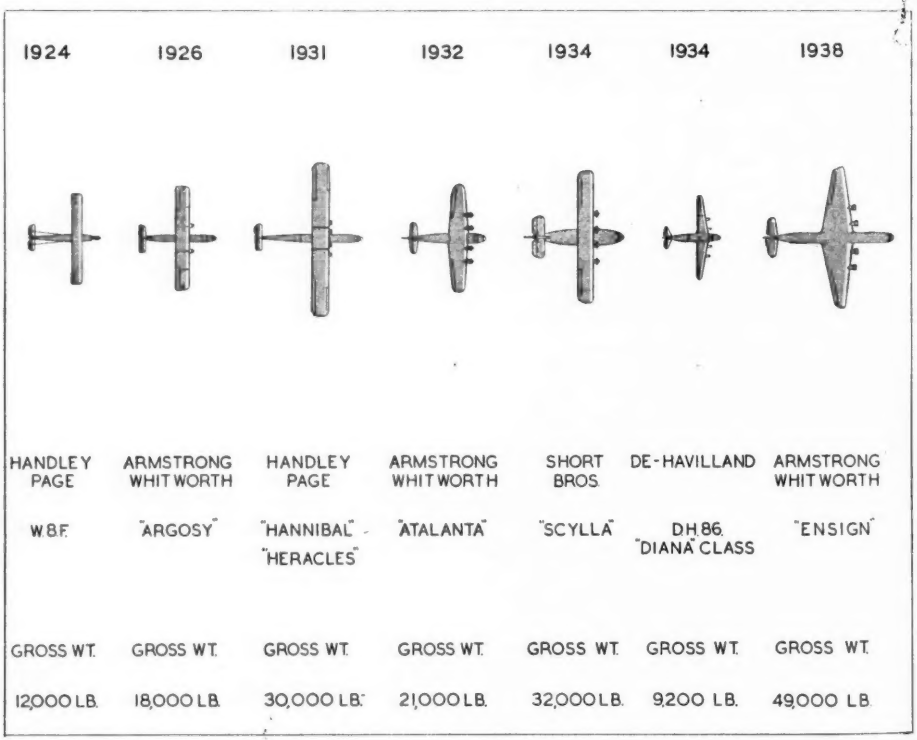


Fig. 13.
Aircraft of the London-Paris route. Imperial Airways.

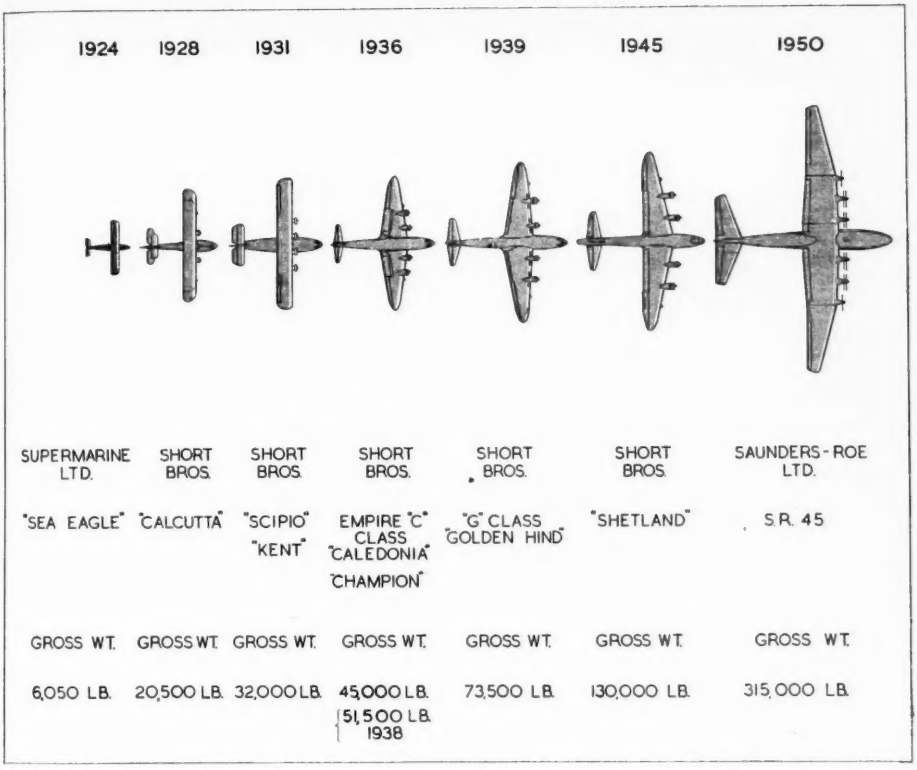


Fig. 14.
Transport flying boats—British.

found most of these destroyed. It was the impetus of war that developed the Zeppelin from a capacity of 706,200 to 2,189,220 cubic feet, and from a speed of almost 50 to 90 miles per hour, and from a useful load of 9 to 44 metric tons.

The *R*.34 made the first Atlantic crossing in 1919.

The *R*.38, of 2,700,000 cubic feet, was planned to be sold to the U.S.A., but on the 24th August 1921 she broke in two in the air.

The *Shenandoah* was first flown in 1923, and was 2,115,174 cubic feet. She broke up in a storm on the 3rd September 1925.

In 1924 the desire for Empire communication prompted the construction of the *R*.100 and the *R*.101, both being of 5,000,000 cubic feet. In July 1930 the *R*.100 flew to Montreal in 79 hours, and returned in 57 hours. On the 5th October 1930, while flying to India, the *R*.101 crashed at Beauvais.

In 1928 the *Graf Zeppelin* was completed. It was of 3,708,600 cubic feet in capacity, and achieved many notable flights, including one round the world with only three intermediatory stops at Tokyo, Los Angeles and Lakehurst, New Jersey.

The *Akron* and the *Macon* were started in 1928; they were both of 6,500,000 cubic feet. The *Akron* crashed on the 4th April 1933. On the 12th February 1935, structural failure of the fin caused loss of control of the *Macon*, and she finally sank in the sea.

The *Hindenburg*, 7,063,000 cubic feet, followed, and in 1936 operated the first commercial air service across the Atlantic. On the 6th May 1937, while landing at Lakehurst, N.J., she was lost by fire.

Her sister ship, the *Graf Zeppelin,* was completed and tested in 1938. Refusal by the U.S.A. to sell helium for her inflation prevented her from being used on the North Atlantic.

Figure 17 shows the striking rate of growth of these aircraft.

I do not wish to consider the subject of "Airship *versus* Aeroplane," but think that I am right in saying that the airship enthusiast saw a future for the really giant type.

In tracing the development of air transport, I have so far not included the ancillaries. Had I been speaking in 1936 my task would perhaps have been easier. I would have said that landplanes required only large flat grass fields, of good surface, and with available runs of 1,500 to 2,000 feet in all directions. Indeed, the minimum requirements in 1935 for an aerodrome were 900 feet by 450 feet. Marine aircraft would have required merely a stretch of water of slightly larger proportions, while the airship need only have been provided with its mooring mast. However, the necessity to improve land aerodromes was beginning to be felt about 1937. The U.S.A. were providing surfaced runways, chiefly on account of their difficulty in growing good grass surfaces. By 1937, then, the 8-way surfaced aerodrome was in use in America, and was being suggested to Great Britain. This was only the beginning, and by 1939 larger aerodromes still, with more expensive surfaces, were being envisaged.

The outbreak of the War obscured the development of aerodromes from the public eye, but we know that it was extremely rapid and expensive. By 1944 the highly-developed aerodrome with its concrete runways as we know it to-day was so taken for granted that

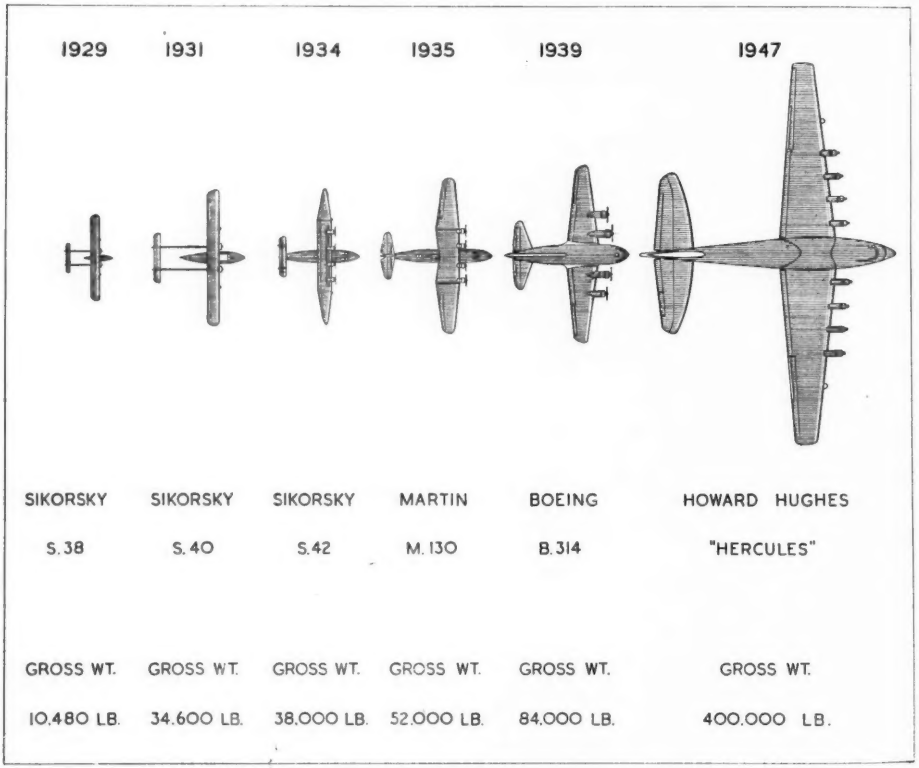


Fig. 15.

Transport flying boats—American.

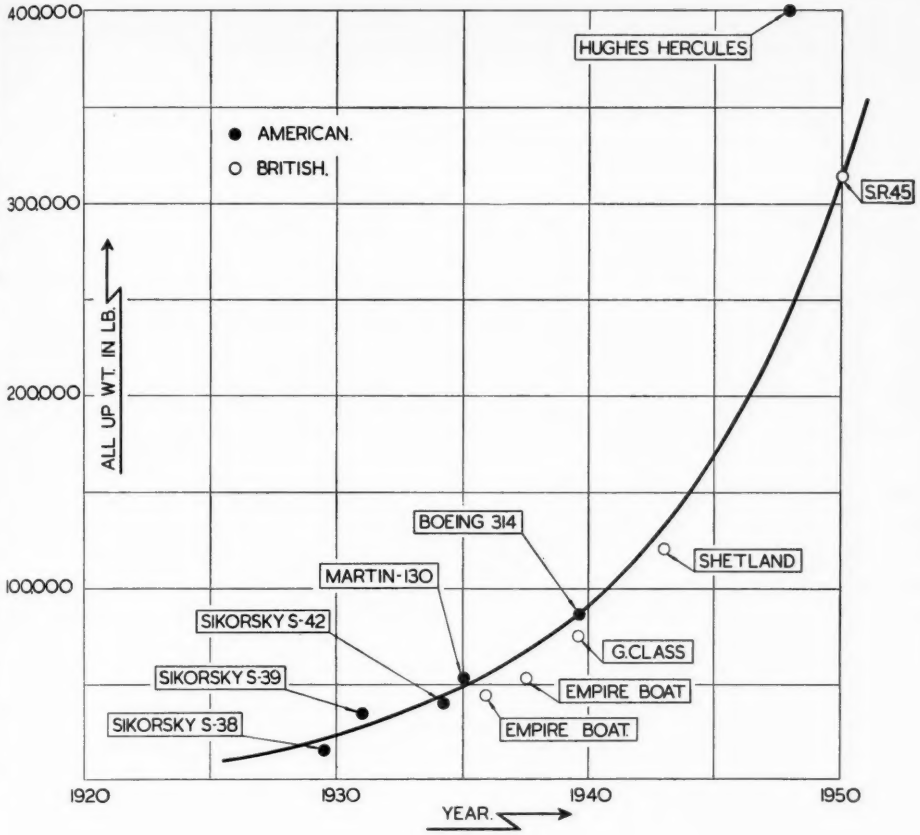


Fig. 16.
Air transport.
Growth of size of flying boats.

in a pamphlet entitled, "Technical Characteristics of Aerodromes, Part 1: Siting and Lay-out of Land Aerodromes," the suggestion for a trans-ocean terminal airport was as follows:—

Maximum gross weight of aircraft: 360,000 lb.
Maximum wing load per square ft.: 63 lb. sq. ft.
Maximum undercarriage track: 100 ft.
Maximum tyre pressure: 120 lb. sq. in.

The runways were to be 15,000 ft. long and 600 ft. wide.

Figure 18 shows pictorially the growth of aerodrome size.

Up to 1936, Croydon was the major airport in Britain.

In 1939 Elmdon Aerodrome at Birmingham was probably the most modern in the country, and had 730 acres; the capital investment in April 1939 was about £550,000.

La Guardia Airport at New York was opened on the 1st December 1939. This was a modern aerodrome with concrete runways. Quite a lot of land reclamation was involved in its construction, and the total cost at that date was given as £10,000,000 (four dollars to the £).

Finally, I have shown the aerodromes of Idlewild and Heath Row; both these aerodromes in their finished condition will cost between £20,000,000 and £30,000,000.

On Fig. 19 I have given curves which further illustrate this point. These show the

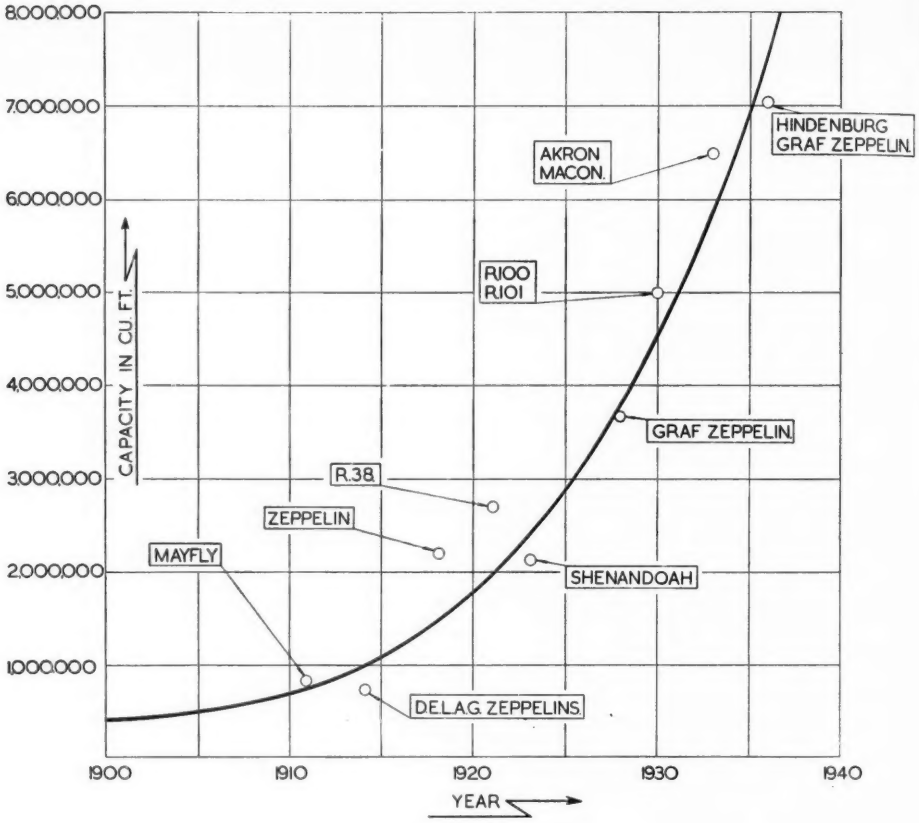


Fig. 17.
Growth of airship size.

increase of runway lengths and cost of aerodrome. This growth has been dictated by the increase in landing speed and in the size of current and projected landplanes. So it seems that aerodrome size is not a static thing, for we read from time to time that aerodromes of comparatively recent design have had to have their runways strengthened to meet the increase in growth. (Prestwick Aerodrome is at present under reconstruction.) Attempts have been made, of course, to limit the size of aerodrome, and so we have had the International Air Conference in Paris to discuss this subject. The possibility, therefore, exists that eventually the necessary ancillary equipment may severely limit the natural growth of the landplane.

With regard to terminals for marine aircraft, there has been little alteration since 1936. Suggestions have been put forward, and Fig. 20 indicates such a marine terminal on the Solent.

5. SIZE IN AIR TRANSPORT.

I have now shown that the natural tendency in the development of transport aircraft of all classes is to grow large like other vehicles, where the volume of traffic warrants it. This, in itself, is a good indication to the non-expert that size means an increase in efficiency and economy. Several eminent aeronautical engineers have in the past shown this to be the case. Before concluding, however, I would like to repeat their arguments in a simpler and perhaps less complete form.

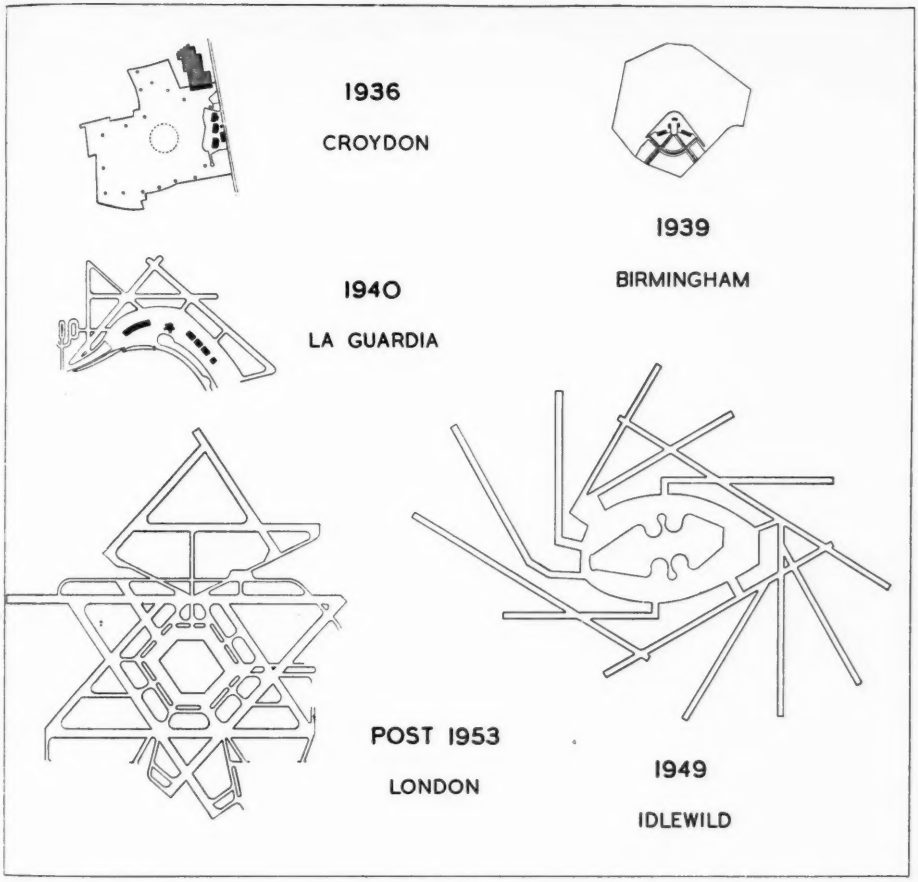


Fig. 18.
Growth of airports.

To begin with, I intend to assume that the lowest value of "lb. of aircraft/passenger" achieved in the design of an aircraft of a specified performance is a satisfactory measure of engineering efficiency. This is an extremely broad assumption, but I think that, for the purpose in mind, it is one which can be provisionally taken.

Let W_{TO} be the all-up weight of the aircraft.

W_{BO} be the weight of the aircraft less fuel and passengers (*i.e.* weight of structure, power plant, crew and equipment).

W_F be the weight of fuel.

W_P be the weight of payload.

Then, for a reciprocating engined aircraft, the range as given by the well-known formula is:—

$$R = \{ [375\eta (L/D)]/c \} \log_e \{ (W_{TO})/(W_{TO} - W_F) \}$$

This formula may be reduced, without much loss in accuracy, to the more convenient form:—

$$R = [375 \,.\, \eta \,.\, (L/D) \,.\, W_F]/[c \{ W_{TO} - (W_F/2) \}]$$

Again:—

$$W_{TO} = W_{BO} + W_P + W_F$$

$$W_P = W_{TO} - W_{BO} - W_F$$

$$(W_P)/(W_{TO}) = 1 - (W_{BO})/(W_{TO}) - (W_F)/(W_{TO})$$

If we assume that the weight for one passenger is 230 lb., then the quantity "lb. of aircraft/passenger" is given by:—

"lb. of aircraft/passenger" =

$$\{ (W_{TO}230)/(W_P) \}$$

$$= 230/ \{ 1 - (W_{BO})/(W_{TO}) - (W_F)/(W_{TO}) \}$$

Now I want to show that, in our experience, this quantity actually decreases with size.

To do this I must show that

$$\{ (W_{BO})/(W_{TO}) + (W_F)/(W_{TO}) \}$$

does not increase with increase in weight.

In Fig. 21 I have shown the variation of $(W_{BO})/(W_{TO})$ against all-up weight of aircraft. You will see that this is actually tending to decrease. This curve represents design experience; that we can continue to beat the infamous square-cube law in this respect I have no doubt.

Consider now $(W_F)/(W_{TO})$, we must prove that this does not increase either.

$$(W_F)/(W_{TO}) = 1/ \{ [375\eta (L/D)]/cR + .5 \}$$

(L/D) is the only variable involved which varies much with increase in all-up weight, and may be written:—

$$(L/D) = \{ C_L/(C_{Do} + kC_L^2) \}$$

The quantity "k" does not vary much with size; it does tend to decrease due to a decrease of interference of such things as engine installations, and so on.

Figure 22 shows the variation of C_{Do} with increase in size. The decrease shown is familiar to all aircraft engineers; it is due to the effects of increase in Reynolds number and a decrease in the ratio of body surface

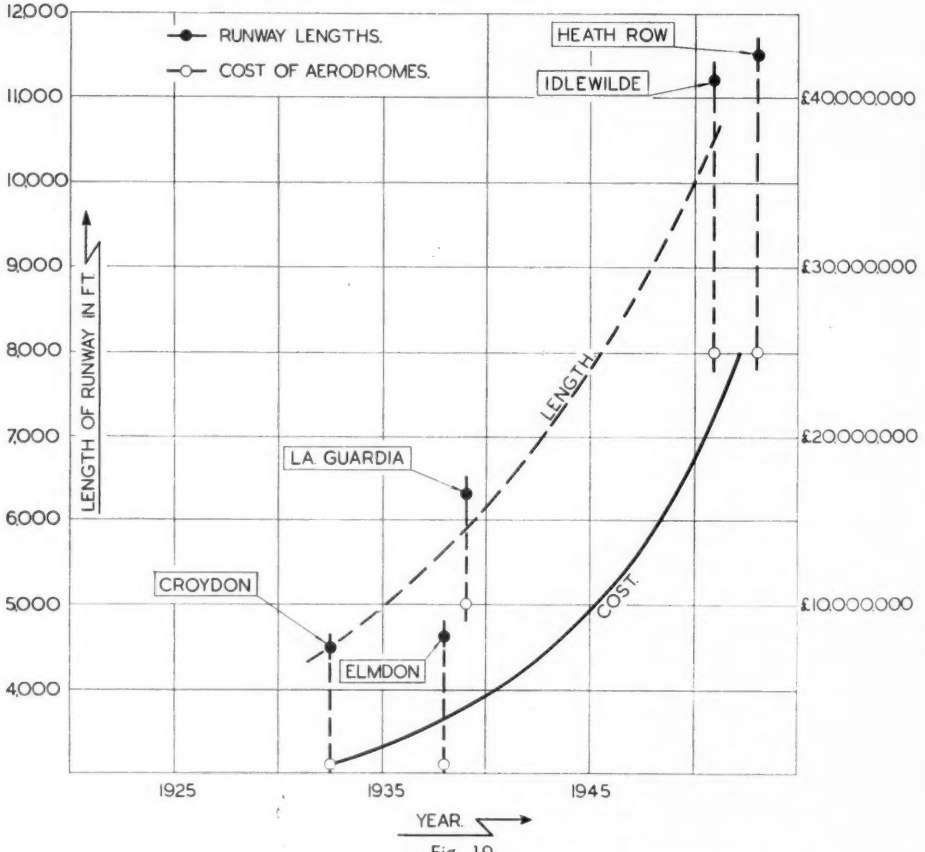


Fig. 19.
Growth of aerodrome runway length and growth of aerodrome cost.

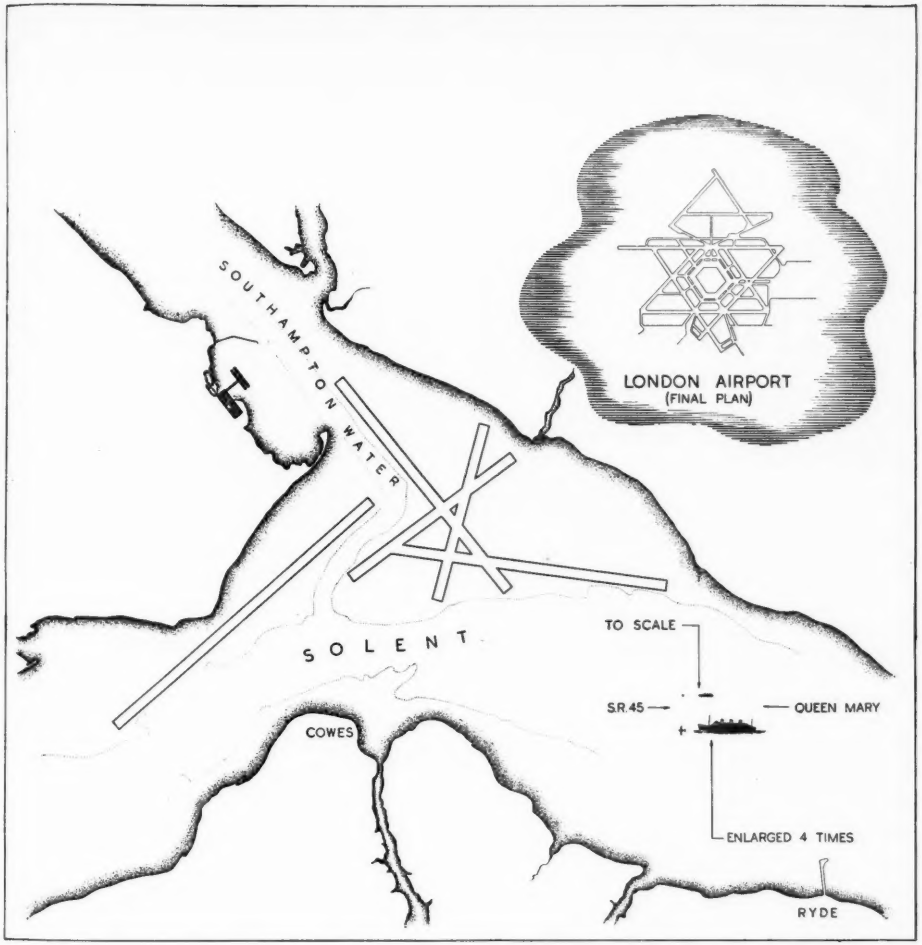


Fig. 20.
Possible landing areas on the Solent (a comparison with London Airport final plan).

area to wing surface area. So we find that (L/D) must tend to increase with size, and consequently $(W_F)/(W_{TO})$ tends to decrease.

In Fig. 23 I have given curves of "lb. of aircraft/passenger" against all-up weight for different ranges. These have been derived from Figs. 21 and 22, together with the assumption of general values for propeller efficiency and specific fuel consumption. A rather high aspect ratio has been taken, and to some extent this is perhaps inconsistent with Fig. 21. However, these curves are only intended to show the advantages to be gained with large machines, especially where long range is concerned, and they apply only to a specific family of aircraft, having reciprocating engines and similar performance.

It has been my purpose throughout this lecture to avoid, as far as possible, technicalities, so that if I neglect to show that the fuel consumption per passenger and other important aircraft characteristics improve with all-up weight, it will be appreciated. Also, what I have said for reciprocating-engined aircraft is true for turbo-props and turbo-jets.

We have now studied the transport problem in general, and have noted how in all cases the vehicles have increased in size as the years went by and as technical advances permitted them to do so. At the outset of this lecture I had intended to give many more examples—for instance, the growth of bombing aircraft, battleships and aircraft carriers —but these are so self-apparent that I omitted them.

I should now like to consider some of the points which I have made earlier in the lecture, and to illustrate these by the consideration of two specific cases of air transport.

These cases are not intended to apply to any particular route, but to indicate and give my personal opinion as to how they should be developed.

Taking, then, the first of these cases, let us consider the provision of air transport between two cities whose population may be counted in millions, and whose distance apart is approximately 250 miles. I have chosen this comparatively short range because I wish, in the other case, to deal with long range. I think that what I am going to say in connection with both of these is applicable to any intermediate range. I am assuming also that the two cities are separated by some geographical obstruction

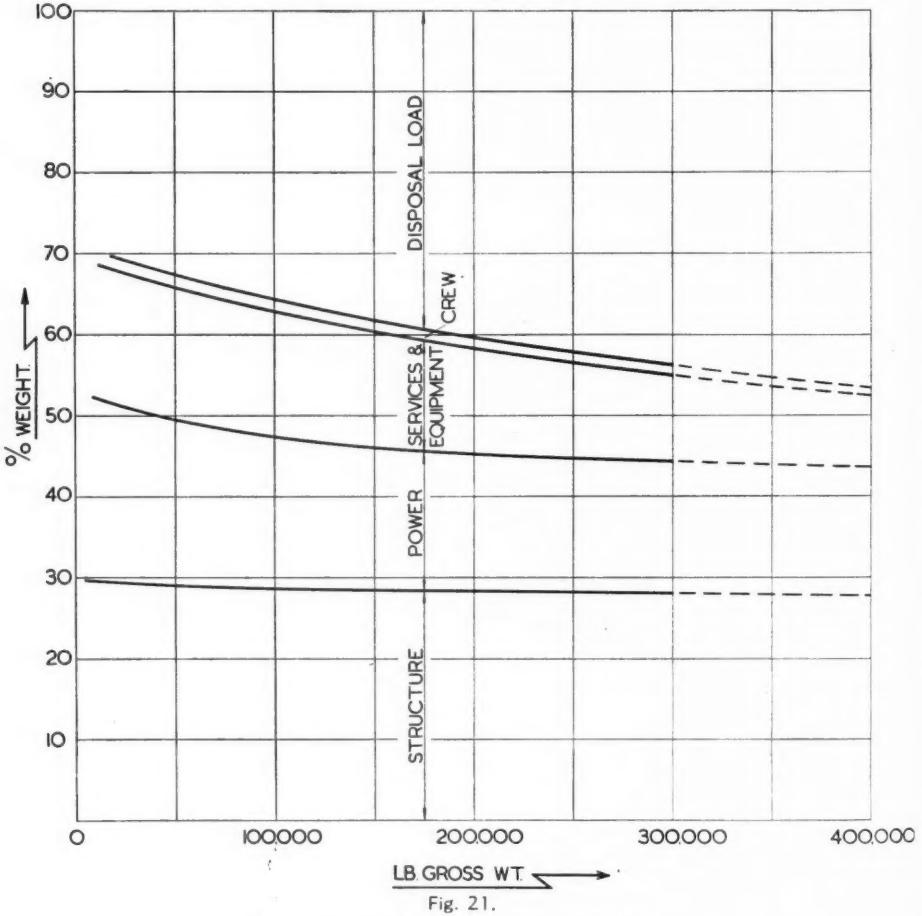


Fig. 21.
Percentage weight breakdown—all-up weight.

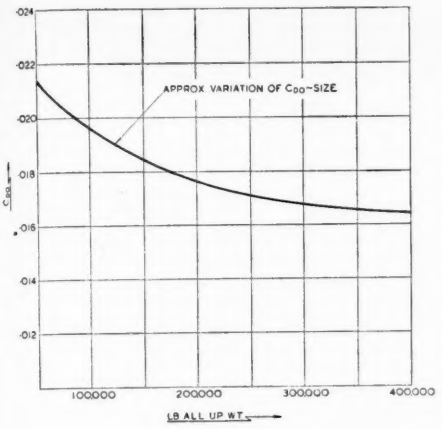


Fig. 22.
Variation of C_{DO}—all-up weight.

which precludes the possibility of a modernised railway system ever competing with regard to speed.

This I consider to be an ideal case for passenger traffic by air, and it should, I think, be possible, if thorough consideration be given to the whole project, to carry eventually almost the whole of the passenger traffic which moves between these two large cities.

If we believe in this, as many of us do, we should design now to make it come true.

The journey time, with machines as we know them to-day, would be in the neighbourhood of one hour: therefore, I would expect that the frequency would be of the order of one hour. The size of the machine would be determined by the volume of the traffic.

I would expect the traffic between these two cities to be, in the long run, in the order of thousands a day rather than in hundreds. It is obvious, therefore, that it is a task worthy of a serious engineering undertaking and, if you agree with me on the question of frequency, you will see that a comparatively large aircraft is necessary. You will also agree that it is a business which can be made a real success.

Therefore I say that the aircraft to be used on this undertaking should be specially designed for the job and for nothing else but the job, and no consideration whatsoever should be given to buying one "off the shelf."

For example, the fact that the range is comparatively short will preclude the necessity for high-altitude flying. Again, if the two cities concerned lie in the temperate zone, I see no reason why the aircraft or engine, or any part of the equipment, should be considered for tropical flying. I think we might even claim a relaxation on such things as the maximum gust intensity to be met. On the other hand, this aircraft, for every hour's flying, will be performing one landing and take-off, and therefore thorough consideration should be given to the design of its undercarriage, and if necessary a particular set of requirements written for it. Furthermore, the engine and the number of engines should be considered from this angle as well, in order that the highest margin of safety possible is achieved under the conditions envisaged. (The largest percentage of fatal accidents with regard to aircraft occur during landing and take-off.)

Continuing on the same subject, as this range is only 250 miles the tankage should meet this, and I would go so far as to say that the project we are considering is sufficiently important that we should not contemplate equipping the machine with tanks for a greater range because we have our eyes on some other market. You will agree that over-sized tanks on a job like this will introduce an element of danger, and it is far easier to provide the right size of tank holding the proper amount, gauged correctly,

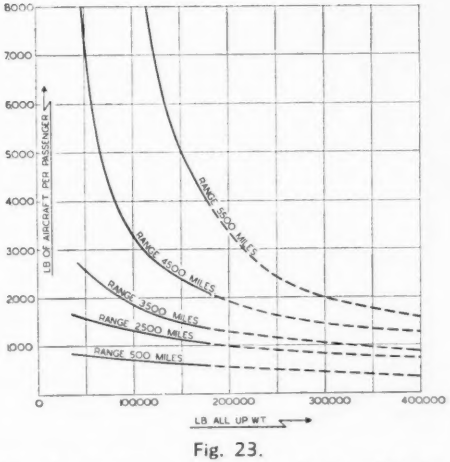


Fig. 23.
Lb. of aircraft per passenger—all-up weight for different ranges.

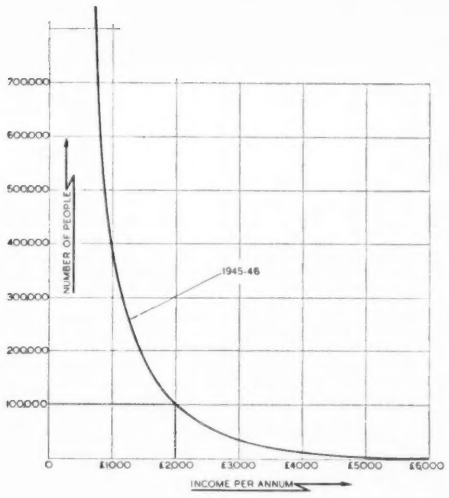


Fig. 24.
Number of persons having incomes over stated amount.

and installed easily. You will also agree that such precision of design requirement will be a great assistance to the designer and his staff, compared with the position in which these unfortunate gentlemen often find themselves to-day—namely, of designing an aircraft for one particular route and having to consider all other routes in the world at the same time. Another great advantage about this is that it will enable the aircraft constructor to turn out a new design in a very much shorter period of time than is possible under the present arrangement.

I realise that it is apparently uneconomical to design a machine of which the number required is in the order of a dozen or so rather than a hundred, but I repeat that we are not giving the proper consideration to the magnitude of the job we are undertaking unless we set out to supply these two cities with air transport worthy of the route.

I feel that the extra cost involved, together with the design effort, is of little importance in comparison with the final undertaking, and, furthermore, I think that at this time in the history of our aircraft industry we are in the position to supply this commodity—namely, a specialised design.

Finally, I would say that the problem envisaged here is of such an easy nature—that is, the transit of a large volume of traffic over a short distance—that the service could be operated by almost anything you choose, even a modified bomber, but to do so would, in my opinion, be fatal. To achieve success, we must design for it.

Turning now to the second case, I want to study briefly the aircraft route which is equivalent to that of the North Atlantic.

This involves a flight of some 3,500 miles and it is generally conceded to be the most difficult service to operate in the world; on the other hand, it has the greatest possibilities. Without visualising a great change in the aircraft conceived to-day, the speeds of the vehicles operating on the North Atlantic would be of the order of 350-400 miles an hour. This would give an average journey time of about nine or ten hours, and consequently I would say that the frequency required would be two or three craft per day. (I should like to remark that where two or three separate companies operate a route, the frequencies to which I refer are with respect to an individual company only.)

In order to lay down proposals for such a service, we should make some quantitative estimate of the volume of traffic to be carried. The populations involved are of an order over the 100 million on each side. Mr. Warner has given us, in 1943, an estimate of 600 a day, and it is interesting to remark that from present statistics he is not far out. However, we can make an estimate based on other considerations, and it is interesting to do so.

Let us assume that most people with an income of about £2,000 a year would be potential travellers, at least once a year, and that they would probably always travel with one companion. Fig. 24 shows the disposition of income in this country, and you will notice that there are almost 100,000 involved. Now, irrespective of other nationalities crossing the Atlantic, we might well expect 200,000 British return journeys per year.

I maintain that it should be our object to provide transport for these people, and consequently we should envisage a density, in the near future, of 600 persons per day. With the frequency I have mentioned before, we should therefore be contemplating the provision of aircraft to carry 200-300 passengers.

In the interests of safety, and using general engineering commonsense, I would say that the journey should be made from point to

point in order to avoid the hazard of intermediate landings and take-offs. So, if you are still in agreement with me, you will see from the range and payload involved that we must be prepared to build in the future much larger sizes of aircraft than we are at present doing.

I now come to this point—you have seen from what I have said before that the size and cost of the aerodrome is becoming prohibitive, and it is doubtful to my mind whether we can, or should go, much farther in this direction. This means that we are limited to land machines of the size of the *Brabazon* or a little larger. If we are limited to this size, then in years to come either the frequency must go up or the potential passengers cannot be carried.

As no doubt we shall do all in our power to extend the service and carry all the

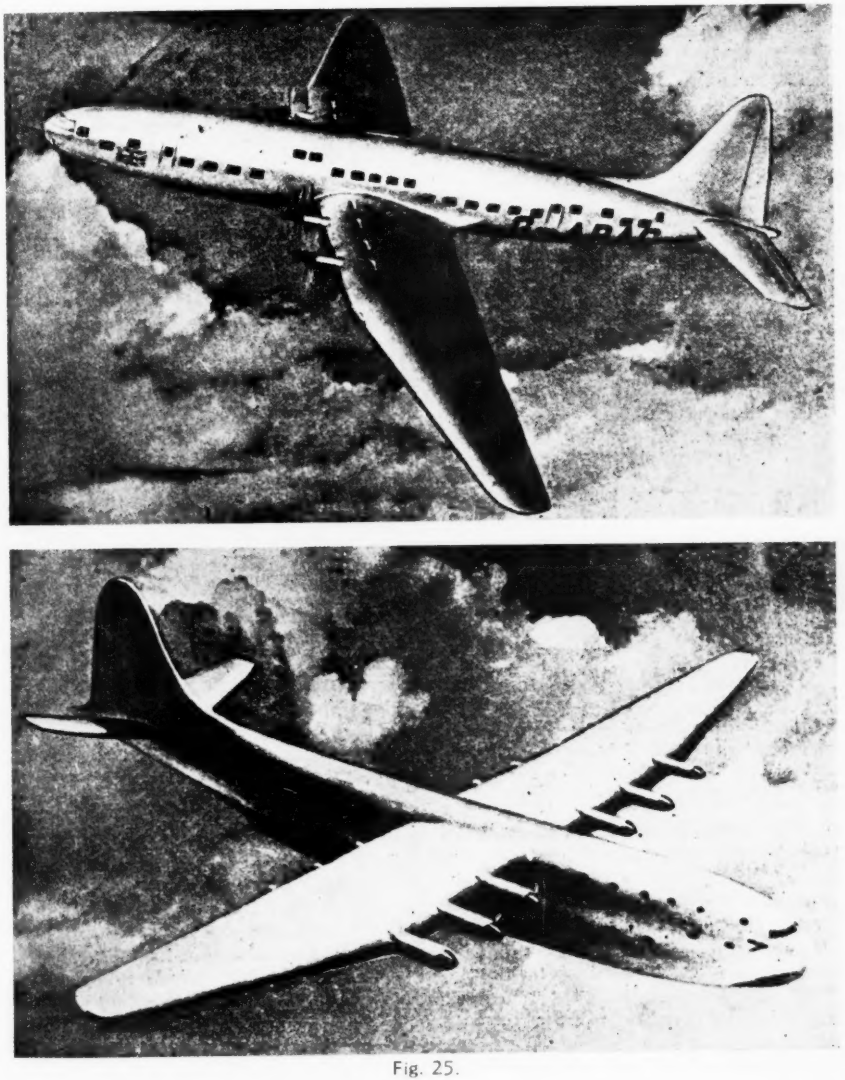


Fig. 25.

passengers becoming available, it is necessary and essential that we develop our large flying boats, irrespective of what anybody else is doing in the matter, because these are the only craft, in my opinion, which can develop in size without an extremely high ancillary cost. Fig. 20 shows the size of landing areas in the Solent, areas which will accommodate a boat very, very much larger than those at present under construction.

Therefore, in this direction we are unlimited and can plan with some confidence to go to such a size as will handle efficiently the vast traffic which will become available across the North Atlantic.

This route will be a highly specialised one, and anything I have said under the first example with regard to specialising for the route can be said in this case, but with much greater emphasis.

The North Atlantic as an air route has such enormous potentialities that we should not in any way confuse the issue by attempting to design a machine for any other purpose than for this particular route. This is the case where it is absolutely essential to specialise.

Naturally, the design of these large machines entails many new problems: these, however, are being rapidly overcome, and I think that we in Great Britain can claim to be in the forefront in giving the world this class of aircraft in the *Brabazon* and the *S.R./45*.

These two machines are illustrated in Fig. 25.

6. CONCLUSIONS.

Now I would like to make the following points:—

(*a*) A study of nearly all forms of transport leads one to the conclusion that the frequency of operation is largely dependent on, and nearly equal to, the journey time.

(*b*) The size of the vehicle (unless it is limited by other considerations) is determined by the potential volume of traffic.

(*c*) We have seen that all forms of transport have grown from small vehicles to the largest possible on the routes under consideration, until the size has been restricted by factors other than the vehicle itself. The largest unit has invariably proved the most efficient.

(*d*) It is essential to provide adequate capital for the ancillaries of flight, but at the same time care must be taken to ensure that the weight of capital used does not, because of its magnitude, attempt to influence the future too far.

(*e*) It is important, wherever the density of population warrants it, to give specialised consideration to each particular route. This is the only way in which to make it really successful.

(*f*) It is technically possible at the moment to design aircraft of larger sizes than are being built now and, in my opinion, these will be more efficient.

ACKNOWLEDGMENTS.

I wish to thank the London Passenger Transport Board, British Railways (Southern Region), and the Cunard White Star Line for the valuable information which they have given regarding their services. Any opinions I may have expressed are, of course, my own.

My thanks are due also to the staff of the Royal Aeronautical Society and to several others, particularly my technical assistant, M. J. Brenan, and my secretary, Mrs. I. K. Wooding.

Sir John Buchanan (Vice-President of the Society, *Fellow*): It was a great pleasure to him to have this opportunity of proposing to his old friend Mr. Gouge, a very hearty vote of thanks for his most excellent paper. Mr. Gouge was no stranger to them. His work on the development of air transport aircraft was well known. His development of the Empire flying boat had opened a new era of communication between this country and the Far East and Australasia. Those boats set up a new standard of safety and comfort which had not been surpassed, if indeed it had been equalled. He was now engaged on another adventure of great magnitude on flying boats and he was sure they all wished him every possible success in his new enterprise. It was with great pleasure that he asked them to accord to Mr. Gouge a warm vote of thanks for his most interesting paper.

Mr. N. E. Rowe (Vice-President, *Fellow*) seconded the vote of thanks. He counted himself privileged to have Mr. Gouge among his friends. Mr. Gouge had greatness of heart as well as those qualities of breadth of mind and vigour and the ability to survey and seize on his problems. The latter qualities had been shown amply in his career. He had done great work in aeronautics over many years and had made great advances, especially on the engineering side.

He had a natural kindness which was evident to all who met him and which had endeared him to a great number of people in the Aircraft Industry. He had also been a great friend to, and an active member of, the Society. His Wilbur Wright Lecture had given them much to think about and it was good to hear an engineer of Mr. Gouge's outstanding ability make such striking forecasts of the future of civil air transport. He had much pleasure in seconding the vote of thanks to Mr. Gouge.

The vote of thanks was carried with acclamation.

Following the lecture the Annual Council Dinner was held at 4 Hamilton Place, at which the following were present:—

L. S. Armandias, Esq., Association Française des Ingénieurs et Techniciens de l'Aéronautique.

Air Marshal Sir Brian E. Baker, K.B.E., C.B., D.S.O., M.C., A.F.C., Air Officer Commanding-in-Chief, Transport Command; Major-General Clayton L. Bissell, Military and Air Attaché, American Embassy; J. W. Booth, Esq., Chairman, British South American Airways; Lord Brabazon of Tara, M.C., F.R.Ae.S., Past President, Royal Aeronautical Society, Member of Council; Sir John S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S., Vice-President, Royal Aeronautical Society; Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., Director for Construction of Research Facilities, Ministry of Supply (Air), Member of Council.

S. Camm, Esq., C.B.E., F.R.Ae.S., Director and Chief Designer, Hawker Aircraft Limited, Member of Council; A. V. Cleaver, Esq., A.R.Ae.S., Special Projects Engineer, de Havilland Engine Company, Member of Council; Air Marshal The Hon. Sir Ralph A. Cochrane, K.B.E., C.B., A.F.C., Air Officer Commanding-in-Chief, Flying Training Command; Air Marshal Sir W. Alec Coryton, K.B.E., C.B., M.V.O., D.F.C., Controller of Supplies (Air), Ministry of Supply; Dr. H. Roxbee Cox, B.Sc., D.I.C., F.R.Ae.S., President, Royal Aeronautical Society.

Gerard d'Erlanger, Esq., C.B.E., Chairman, British European Airways; Dr. G. P. Douglas, O.B.E., M.C., F.R.Ae.S., Head of Aerodynamics Department, Royal Aircraft Establishment, Member of Council; Marshal of the Royal Air Force Lord Douglas of Kirtleside, G.C.B., M.C., D.F.C.

A. G. Elliott, Esq., C.B.E., M.S.A.E., F.R.Ae.S., Director and Chief Engineer, Rolls-Royce Ltd., Member of Council; Air Marshal A. B. Ellwood, C.B., D.S.C., Air Officer Commanding-in-Chief, Bomber Command.

Sir Richard Fairey, M.B.E., F.R.Ae.S., Past President, Royal Aeronautical Society; W. S. Farren, C.B., M.B.E., M.A., F.R.S., M.I.Mech.E., F.R.Ae.S., Member of Council, Technical Director, A. V. Roe, Ltd.; Sir A. H. Roy Fedden, M.B.E., D.Sc., M.I.Mech.E., M.S.A.E., F.R.Ae.S., Past President, Royal Aeronautical Society.

Colonel B. af Geijerstam, Chief of the Engineering Division, Royal Swedish Air Board; A. Gouge, Esq., B.Sc., M.I.Mech.E., F.R.Ae.S., Wilbur Wright Memorial Lecturer 1948, Vice-Chairman, Saunders-Roe Limited, Past President, Royal Aeronautical Society; Major William Gregson, M.Sc., M.I.Mech.E., President, Institution of Mechanical Engineers.

Professor A. A. Hall, M.A., F.R.Ae.S., Zaharoff Professor of Aeronautics, Imperial College of Science, Member of Council; S. Scott Hall, Esq., A.C.G.I., M.Sc., F.R.Ae.S., Principal Director of Technical Development (Air) Ministry of Supply, Member of Council; Sir Harold Hartley, K.C.V.O., C.B.E., M.C., F.R.S., Chairman, British Overseas Airways Corporation; Air Chief Marshal Sir Edgar Ludlow Hewitt, G.C.B., C.B.E., C.M.G., D.S.O., M.C., Chairman of the Board of Governors, College of Aeronautics; E. W. Hives, Esq., C.H., M.B.E., F.R.Ae.S., Managing Director, Rolls-Royce Limited, British Gold Medallist for Aeronautics, 1948; J. E. Hodgson, Esq., Hon.F.R.Ae.S., Honorary Librarian, Royal Aeronautical Society.

Monsieur J. Jarry, President, Association Française des Ingénieurs et Techniciens de l'Aéronautique; E. T. Jones, Esq., O.B.E., M.Eng., F.R.Ae.S., Director of Instrument Research and Development, Ministry of Supply, Member of Council; Sir Bennett Melvill Jones, C.B.E., A.F.C., F.R.S., Hon.F.I.Ae.S., F.R.Ae.S., Francis Mond Professor of Aeronautical Engineering, University of Cambridge, Royal Aeronautical Society Gold Medallist, 1948.

G. S. Lindgren, Esq., M.P., Parliamentary Secretary to the Ministry of Civil Aviation; Sir Ben Lockspeiser, M.A., F.C.S., F.R.Ae.S., Chief Scientist, Ministry of Supply, Member of Council; Captain René Lucien, F.R.Ae.S., Association Française des Ingénieurs et Techniciens de l'Aéronautique.

P. G. Masefield, Esq., M.A., F.R.Ae.S., Director General of Long Term Planning and Projects, Ministry of Civil Aviation, Member of Council; Major R. H. Mayo, O.B.E., A.M.Inst.C.E., F.R.Ae.S., President, Air League of the British Empire; Colonel Guy du Merle, F.R.Ae.S., Chef de Service Technique, Ministere de l'Air.

The Rt. Hon. The Lord Nathan, T.D., D.L., J.P., Minister of Civil Aviation.

Sir Arnold Overton, K.C.B., K.C.M.G., M.C., Permanent Secretary to the Ministry of Civil Aviation.

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The 749th paper read before the Society—on the 15th April 1948 at the Institution of Civil Engineers, Great George Street, London, S.W.1. In the Chair, the President, Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S.

VISUAL AIDS FOR LOW VISIBILITY CONDITIONS

A Discussion of the Fundamental Requirements, with a brief account of some results obtained on the R.A.E. Simulator

by

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In 1925 *he joined Metropolitan-Vickers Electrical Co. and completed a two year course as a College apprentice, after which he served in the Transformer Design Department as Junior Engineer.*

He joined the Eelectrical Engineering Department, Royal Aircraft Establishment, as a Technical Officer, in November 1928 *and was employed mainly on aircraft lighting. Since* 1941 *he has been head of the Illumination Section.*

In January 1946 *he was nominated to represent the Royal Aircraft Establishment on the Ministry of Civil Aviation Airfield Lighting Committee, and it was at their request that most of the work described in the paper was done.*

1.0. INTRODUCTION.

THIS paper describes some work, mainly of a theoretical nature, done at the Royal Aircraft Establishment, Farnborough, during the years 1946-1947. The immediate object of this work was to establish some general principles for the guidance of the Ministry of Civil Aviation Airfield Lighting Committee, which is the body charged with the task of deciding what visual aids shall be installed on the civil airports of this country. The work is far from completion and from the scientific point of view, this account of it must necessarily leave some loose ends, but it is felt that the method of attack and the underlying ideas may prove useful to other workers in this field. If this should prove to be the case, then international standardisation will have been brought a little nearer, and as will be made clear in this paper, this is almost as necessary for the visual aids as for the radio aids.

The visual aids consist of day markings and lights laid out on the ground in patterns which are intended to assist the pilot in making those judgments of height, distance, and direction, which are necessary in order that he may approach the runway, land on it, and taxi to the unloading point. Any discussion of the visual aids therefore, involves the question of how the pilot makes these judgments, and it may be considered a little presumptuous, perhaps, for a non-pilot like the author to put forward any opinions on this. To anyone who holds this view, the author would suggest that the mental mechanisms used by the pilot are probably not fundamentally different from those which anyone uses for finding his way about the world, and for controlling vehicles other than

aircraft. Everyone is so accustomed to making visual judgments from childhood onwards, that the making of them has become instinctive and subconscious, and it is rare to find anyone who possesses sufficient insight into his own mental processes to enable him to explain convincingly and intelligibly how he makes them.

The explanations given in this paper are based partly on conversations with flying instructors whose job has forced them to give some thought to these matters, and partly on the author's own experience examined introspectively, but the subject is so complicated that some aspects of it may have been overlooked, or not given sufficient weight. The author is convinced that a systematic study of this problem would pay handsome dividends in increased safety, and the main object of this paper is to stimulate interest in it, and show that even a preliminary study of it can lead to results of considerable practical importance.

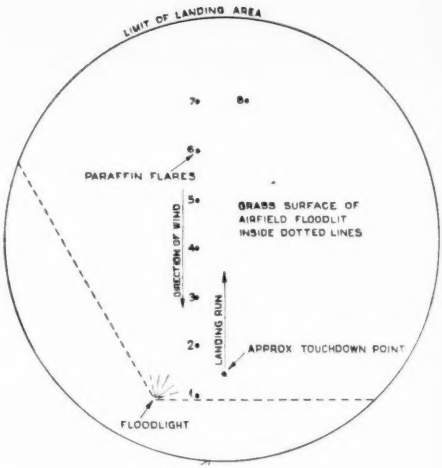


Fig. 1.

Visual aids used on military airfields prior to 1938. Spacing of flares dependent on size of airfield.

2.0. BRIEF ACCOUNT OF THE VISUAL AIDS USED IN THIS COUNTRY BEFORE AND DURING THE WAR.

Before 1938 military airfields in Great Britain were grass surfaced, and were quite small compared with those in use at the end of the war. The standard visual aids were a line of paraffin flares to indicate wind direction, and a floodlight to illuminate the surface of the airfield. In addition, most aircraft by 1938 carried landing lamps which illuminated the surface of the airfield from about 50 feet downwards. For landing the floodlight was placed on the leeward side of the airfield, and the aircraft landed more or less down the beam, and to the right of the line of flares. This system is shown in Fig. 1.

The older generation of present-day pilots learned to land on this system, and many of them still maintain that in good weather, easier and better landings can be made on it than on any other. The writer believes this to be true, for the reason that the principle behind this system is to turn night into day, thereby enabling the pilot to make his judgments using substantially the same technique by night as by day.

The method of landing was to circle the airfield and then make an approach by watching the line of flares and noticing the pattern formed by this line and the horizon. Height just before touch-down was judged by noticing the angular size of known objects on the ground, such as the flames from the flares, the area of ground illuminated by the flares and sometimes, the personnel attending them, and finally, the blades of grass on the surface of the airfield. If the diameter of the airfield did not exceed three quarters of a mile, objects at the edge, such as houses or trees, were also illuminated by the floodlight, and this materially assisted the pilot in making his judgments. In other words, the approach was judged by observing the behaviour of a distant pattern of lights, and the final touch-down was judged by observing both the behaviour of distant objects and the "texture" of the immediate foreground. This idea of texture in the visual aids is a most important one, and lies at the root of several of the practical suggestions put forward in this paper.

For military purposes, this system had the obvious disadvantage that it gave poor security against the operations of intruder aircraft, firstly because floodlights and landing lamps reveal the presence of an airfield at great distances, and secondly, because the flarepath cannot be centrally switched. Apart from this, the system has two other

disadvantages which render it almost useless for modern conditions, as follows:—

(a) The presence of even a little ground mist deprives the floodlight and landing lamp of their usefulness.

(b) A hard surfaced runway without day markings has very little texture, and floodlighting is therefore less effective than on a grass surface. In any case, runways are now so long that they cannot be floodlit from one end.

As soon as operations began, the disadvantages of this system were immediately obvious, and the first year of the war was one of experiment and development. During this period many stations installed temporary electric flarepaths of their own manufacture, which were connected to the station supply through buried cables and were controlled from a post on the airfield. Perhaps the most famous of these temporary systems was that installed at Drem, as this included a number of important features which were included in the system finally evolved.

Figure 2 shows the Drem installation as it was in October 1940. Approach lights consisting of six lights arranged in a 90° vee were used, and as far as the writer is aware, this was the first operational use of approach lights. The corners of the runway were marked by "totem poles" which showed red outwards towards the boundary of the airfield and white along the runway. Three lights marked the left edge of the runway, the middle light being duplicated to indicate that touch down must be made before reaching this point. The assembly point was marked by blue lights, as it was supposed that this colour gave the best security for a given intensity. The floodlight, which was placed between the end of the runway and the first runway light, was switched on as the aircraft neared the runway, and off immediately after touch down.

Approaches at a constant angle could be made by means of an "angle of approach light," which was a light having three coloured sectors arranged one above the other, so that the pilot saw a red light if the aircraft was too low, a green light if the aircraft was approaching at the correct angle, and a yellow light if the aircraft was too high. All the intensities were low, *i.e.* that of the approach lights was of the order of 60 candles and that of the runway lights was about 15 candles. Both the runway and the approach lights could be dimmed.

Several features of this system are worthy of particular notice. In the first place, it is the approach lights and not the runway lights

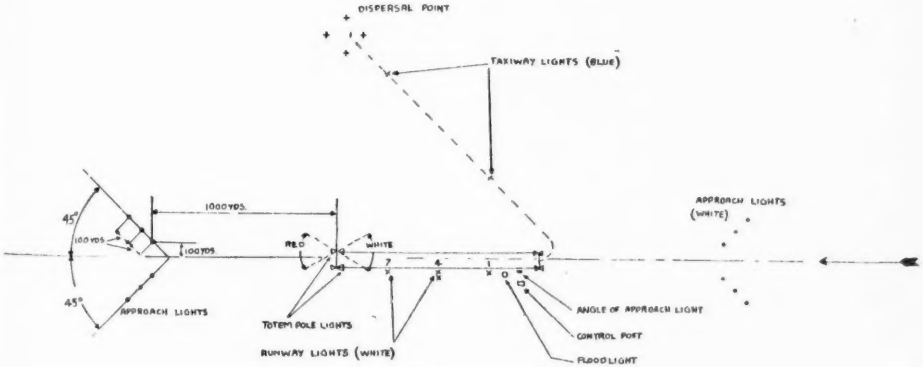


Fig. 2.

Lighting equipment at Drem Aerodrome.

Approach lights—60 watt lamps in bulkhead fittings. Visible all round.
Runway lights—15 watt lamps. Visible 15° above horizontal and 30° in azimuth.
Totem poles—5 lights arranged as vertical bar. Same lamps and cut-off as runway lights.
Floodlight—Consumption 4 k.w. Maximum intensity 1,000,000 candles. Horizontal divergence 100°.
Angle of approach light—Yellow upper sector, green middle sector, red lower sector.

which are visible all round. This gives better security, and the lights serve as a distance marker indicating where to turn in for the approach. In the second place, a number of lights arranged in a distinctive pattern are used to mark the corners of the runways. Provided that this pattern is kept fixed, these lights help the pilot in making his judgments of height and distance as he nears the threshold of the runway. In the third place, approaches can now be made by watching the angle of approach light, and no doubt this method of approach was used by inexperienced pilots until they became familiar with the appearance of the runway lights at various stages of the approach. Many experienced pilots state that they ignored the angle of approach light, and made their approach by watching the pattern formed by the runway lights and the horizon, which means that they used substantially the same approach technique as before.

The next step was to add a circle of lights round the airfield. This feature was particularly popular with pilots because it made the airfield easier to find. It was also of great assistance to the airfield controller, as it enabled him to space aircraft round the circle while they waited for their turn to land. The effectiveness of this "outer circle," as it was called, depended on the blackout, but for the conditions of the time, it was certainly a most useful aid. What was known as "Drem lighting" consisted of the scheme shown in Fig. 2, with the outer circle added, and with additional lights along the left side of the runway. This system, the official name for which was Airfield Lighting Mark I, was installed on only a few airfields, and most of these were later converted to Airfield Lighting Mark II.

In Airfield Lighting Mark I the outer circle passed through the approach lights. As a result of flying experience during 1941 the diameter of the circle was increased and a string of lights was added leading from the circle to the approach lights, as shown in Fig. 3. Also, two extra distance markers were added in the approach, and the three markers were known as outer, middle and inner funnels. In addition, the intensity of the outer circle, lead-in, and funnel lights was increased from about 60 to about 120 candles by using two 60 watt lamps in each fitting instead of one. Lastly, and probably most important of all, it was discovered that a double line of lights, *i.e.* one down each side of the runway, was a pattern which by itself enabled height to be judged with sufficient accuracy for safe touch down. Floodlights therefore became unnecessary, and soon ceased to be used. It is also probable that the "totem poles" also became unnecessary, but as opinions varied about this, they were retained. This system, which was known as Airfield Lighting Mark II, was then installed on all runway airfields, and its basic patterns remained unchanged for the rest of the war.

3.0. LIMIT OF USEFULNESS OF AIRFIELD LIGHTING MARK II.

In order to make an approach on this system, the pilot located the outer circle by visual or other means, and followed it until he picked up the lead-in string, funnels and runway lights. He then turned in through the outer funnel and straightened out for the final approach which, as mentioned above, he usually judged by watching the changing appearance of the pattern formed by the runway lights and the horizon. In order to turn in correctly, he had to see the circle and funnel lights for about a mile ahead, or perhaps a little more, and in order to judge the final approach he had to see the runway lights from about a mile away, or perhaps a little less.

It may be seen from Fig. 4 that the outer circle lights gave a range of one mile at night when the meteorological visibility[1] was about 0.9 mile, and the runway lights gave a range of one mile when the meteorological visibility was about 1.8 miles. This system was useful therefore only at night, and only down to the condition known as "poor visibility" on the international code. Moreover, even in clear weather, the ease of picking up the outer circle largely depended on the absence of extraneous lighting.

Since the intensity of some street lighting installations may exceed 2,000 candles in directions just above the horizontal, it is clear that the usefulness of these outer circles largely ended with the end of the blackout.

[1]Strictly speaking the meteorological visibility is the distance at which a very large dark object can just be seen in daylight. In drawing range diagrams, this is conventionally taken as the distance over which the atmospheric transmission is two per cent.

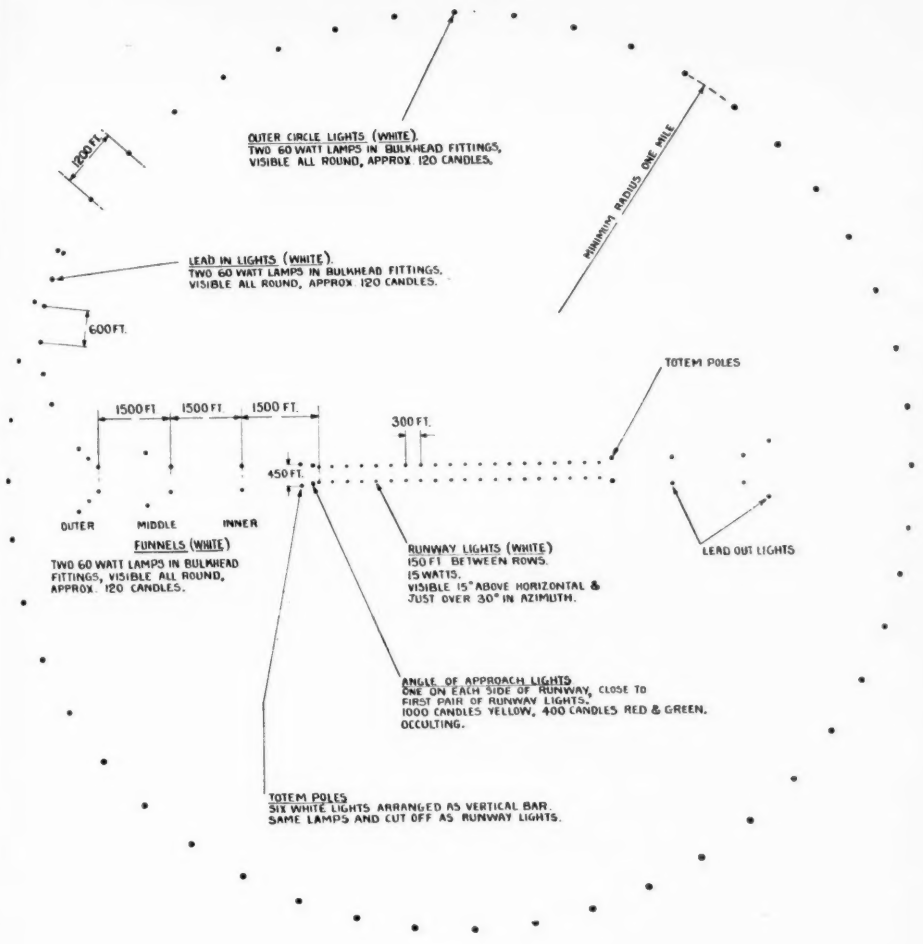


Fig. 3.
Airfield Lighting Mark II. One runway only shown.

In any case, the whole pattern is unsuitable for use with the radio approach aids and the methods of traffic control which are likely to be used at civil airports. It will be realised from all this, that the task of modernising the visual aids on all these airfields is formidable, and that the whole question must be given the most careful consideration. If the principles put forward in this paper are accepted, modernisation can be accomplished without tearing up the concrete on the runways, and the cost will be reasonable.

4.0. VISUAL AIDS FOR USE IN DAYLIGHT.

In good and moderate visibility the best daylight approach aids are white or yellow markings on the runway, but for convenience, discussion of this aspect of the problem will be deferred to a later stage of this paper.

As the visibility gets worse, a point is reached at which the runway ceases to be visible at a distance sufficient to enable a visual approach to be made, and this distance

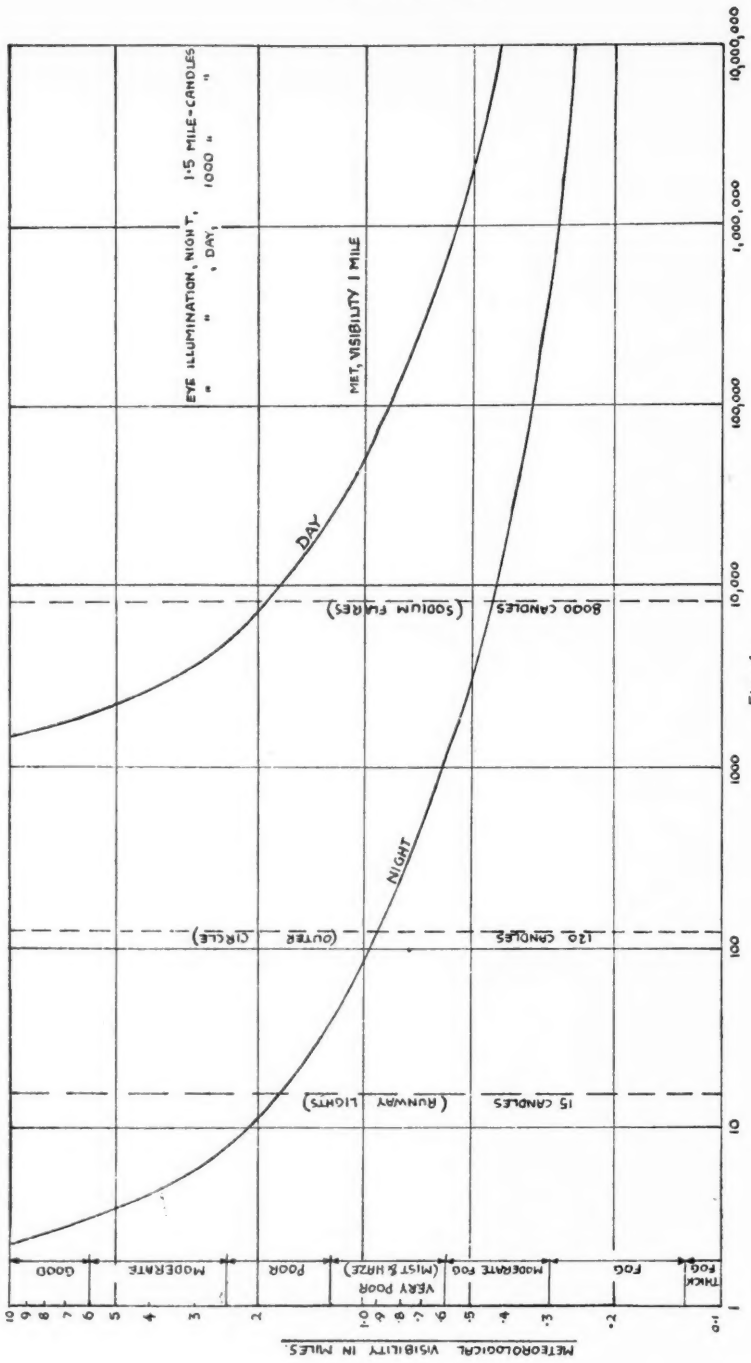
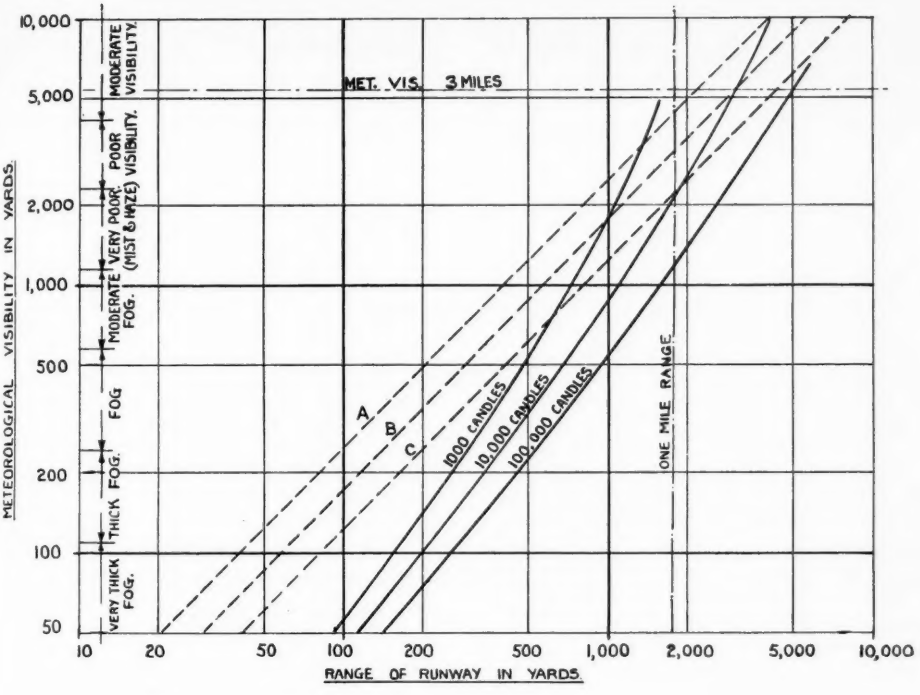


Fig. 4.

Intensity in candles for range of one mile.

Curve giving intensity required for range of one mile in various atmospheric conditions.



——— Range curves of lighted runway
— — — Range curves of unlighted runway
Curve A=0.1 difference in reflection factor between runway and surround
Curve B=0.2 „ „ „ „ „ „ „ „
Curve C=0.5 „ „ „ „ „ „ „ „

Fig. 5.
Comparative ranges of runway, lighted and unlighted, in daylight.

as in the case above, may be taken as one mile. For a given meteorological visibility it is not possible to say at exactly what distance the runway will be seen, as this depends on such factors as the reflectivities of the runway and its surroundings, the direction in which the sun is shining, the time of day and so on, but as a rough guide, it may be taken that in this country, the runway is visible for about a mile when the meteorological visibility is three miles.

From Fig. 4 it may be seen that in this visibility, a range of one mile in daylight can be obtained from lights having an intensity of 5,000 candles. In visibilities worse than three miles, lights of this intensity will be seen at greater distances than the runway, the relationship between the two distances being approximately as shown in Fig. 5. Lights of more than 5,000 candles can therefore constitute a useful daylight aid.

The Royal Air Force discovered this in 1942 by noticing that they could easily find the airfields where synthetic day-night training was in progress, when conditions were such that they had difficulty in finding their own airfields, the reason being that a sodium flarepath was used as part of the day-night equipment. As a result of this discovery, the use of sodium flarepaths spread rapidly throughout Bomber Command. This was the origin of the well-known Sodium Flarepath, Type F, which, since the flares gave an intensity of about 8,000 candles, may be

regarded as the first high intensity landing aid to be used in daylight in this country.

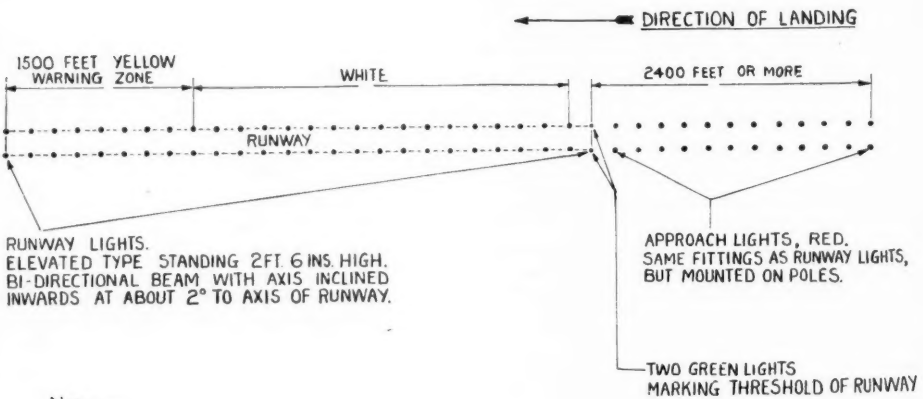
Because of their yellow colour and their large size, *i.e.* about two feet by one foot, these sodium flares are very distinctive, particularly when seen against a background of bluish haze or morning mist. Their light output per watt is very high, *i.e.* about 70 lumens per watt as against 6 lumens per watt for yellow light obtained by filtering an incandescent source. This high efficiency means that wide angles of the order of 120° horizontally by 30° vertically can be covered without using more than 150 watts per fitting and this, in turn, means that the flares are suitable for use as short-range aids to navigation, that is, for marking fixed points. They are now commonly used by the R.A.F. as daylight markers, and they are very effective, particularly in the dull misty weather which is so common in these islands.

A light of 8,000 candles has a daylight range of one mile in a meteorological visibility of two miles, and this may therefore be regarded as about the limiting condition in which visual approaches can normally be made on the sodium flarepath. If the intensity is pushed up to 100,000 candles, then the limiting condition can be lowered to a meteorological visibility of about 0.85 mile. Beyond this point, enormous increases in intensity are required to effect much improvement and it becomes clear that an answer to the problem of daylight landings in really bad weather can never be found by increasing the intensity of the runway lights, even if dazzle could be prevented.

The obvious all-weather solution is therefore to lay down a pattern of high intensity lights in the approach zone, and to feed the aircraft into this pattern by means of a radio approach aid. The radio aid is then relied upon to bring the aircraft down to a height of about 200 feet in the worst conditions in which the visual aids are usable, and the problem is to make the visual aids link up smoothly with the radio aid at about this point.

5.0. FIRST ATTEMPTS TO DESIGN HIGH INTENSITY VISUAL AIDS TO WORK WITH RADIO APPROACH AIDS.

The possibility of combining the two aids to form what is now called an "integrated landing system" was beginning to be generally


DIRECTION OF LANDING
1500 FEET YELLOW WARNING ZONE
WHITE
2400 FEET OR MORE
RUNWAY
RUNWAY LIGHTS.
ELEVATED TYPE STANDING 2FT. 6 INS. HIGH.
BI-DIRECTIONAL BEAM WITH AXIS INCLINED INWARDS AT ABOUT 2° TO AXIS OF RUNWAY.
APPROACH LIGHTS, RED.
SAME FITTINGS AS RUNWAY LIGHTS, BUT MOUNTED ON POLES.
TWO GREEN LIGHTS MARKING THRESHOLD OF RUNWAY

Notes:—

Distance between lights in a row, 200 ft.
Distance between rows = width of runway + 20 ft.
Power consumed per fitting usually 200 watts (some later models 300 watts).
Approximate divergence of beam, 1° at maximum intensity; 4° at 1/10 maximum intensity.
Approximate maximum intensity, 35,000 candles, white; 7,000 candles, red and green.

Fig. 6.

Bartow high intensity lighting system as used in 1944.

realised in America just before the war.[2] Much of the credit for first showing what could be done with lights must go to Mr. J. B. Bartow, who devised the system shown in Fig. 6. In the summer of 1943 this was tested by a joint group of the American Army and Navy at an airfield in Newfoundland where fog conditions were prevalent, radio aids being used for making the initial approach. These tests showed that high intensity lights used in this way constituted a useful aid both by day and by night and during the last years of the war, many installations of this system were laid down, some of them in this country.

In really bad visibility, the technique of making the final approach on a continuous string of lights is quite different from the techniques discussed previously, firstly because the runway lights are invisible for most of the approach and secondly, because the horizon is ill-defined or non-existent. It was widely supposed that if a pilot were able to see three or four lights ahead of him, he would somehow be able to complete his approach. On this supposition, pilots who were skilful enough to make an accurate initial approach by radio down to 200 feet should have been able to land on the lights in meteorological visibilities of the order of 200 yards by day and 100 yards by night, provided that the aircraft had a reasonably good downward view. A few very experienced pilots have done this under test conditions, but the reports available to the author indicate that these landings were attended by far more risk than could be accepted under operational conditions.

Even in better visibilities, many pilots found difficulty in changing over from instruments to lights and complained that the lights seemed to play tricks.[3] For instance, on first picking up the lights the pilot, in correcting a lateral error, might find that the lights seemed to slip sideways away from him, or even appeared to swing from side to side. Also, since the light sources were small enough to appear as points, there was nothing except differences in intensity to indicate which lights were far off and which were near, and even this indication was faulty because of the narrow divergence of the beams.

Since the lights had no appreciable size, no use was made of one of the chief mental mechanisms which everyone uses in order to find his way about the world, namely, the observation of the texture of the foreground, or to put it in another way, the observation at short range of objects whose real size and shape are known. The result was that the psychological obstacles to quick interpretation were increased, an effect which is particularly dangerous to a pilot suffering from fatigue, worry, or other distraction.

Finally, since this pattern gives no indication of whether or not the aircraft is over-shooting or under-shooting until the runway lights come into view, the meteorological visibility at which this pattern ceases to be safe for operational use is about 900 yards in daylight, or about 300 yards at night. This applies more or less to all systems consisting merely of single or double lines parallel to the extended centre line of the runway.

It is obvious that the divergences of the beams given by the fittings used in any approach lighting system must be sufficient to cover the errors which less skilful pilots may make in the radio portion of the approach, and also any errors in installation. In the original Bartow system, the divergences[4] were much too small, *i.e.* about 2° horizontally at 50 per cent. of maximum intensity as against about 100° for the Sodium Flarepath, Type F. A divergence of 2° is hardly sufficient to cover errors in installation and maintenance and, after a few months, most installations of this system which the author has seen presented an uneven and ragged appearance, even when the approaches were made accurately along the centre line.

In most of the systems now under test in America the beam divergence has been substantially increased, in some cases up to 50° horizontally, but in spite of this none, so far as the author is aware, has been generally accepted as meeting operational requirements.

[2]For a detailed account of early developments in America, see paper entitled "Development of Approach and Contact Light Systems," by F. C. Brackenridge and C. A. Douglas, which appeared in "Illuminating Engineering," November 1945.

[3]See article entitled "All-Weather Flying" by F. R. Stout in the American publication "Flying" for November 1947.

[4]In this paper the word "divergence" is used to denote the total spread of the beam.

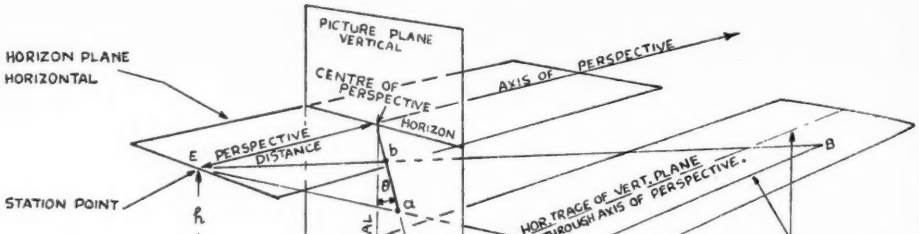


Fig. 7.

Diagram showing planes used in perspective projection. Perspective projection of AB is ab.

In one of the latest systems, krypton-filled flash discharge lamps are being used in combination with suitable reflectors to give flashing signals having a maximum peak intensity of about 3,300 million candles, the duration of the flashes being 17 micro-seconds.[5] For short flashes, *i.e.* flashes shorter than 1/50th of a second, the threshold visibility depends on the integrated candle-seconds. The candle-seconds in the flashes obtained from these krypton lamps are substantially less than the product of the maximum peak intensity and the flash duration, *i.e.* less than 56,000. A value as high as this could be obtained from incandescent lamps in suitable reflectors, and a direct comparison of this kind was made at the Royal Aircraft Establishment about a year ago. In addition, the whole process of producing light by means of flash discharge lamps supplied from condensers is not particularly efficient and therefore there is no significant saving in power to offset the heavy cost. Apart from cost, it is doubtful if pilots will welcome having to make their visual judgments by means of flashing lights. As holding a course and correcting errors is a continuous operation, it is to be feared that these lights will play even more "tricks" than the fixed ones do.

[5]See article entitled "Landing Airplanes in any Weather" by W. A. Pennow in "Westinghouse Engineer" for July 1947.

In order to get to the bottom of these "tricks," and to try to find a pattern which the pilot can interpret instantly, instinctively, and correctly, down to a meteorological visibility of 200 yards in daylight, the author devised a method of attack on the problem which consists in making diagrams showing in outline exactly what the pilot sees at various stages of the approach and landing, including bad approaches as well as good ones. Apart from their value to the technician, these diagrams are of the utmost assistance in keeping discussions of the visual aids in touch with reality, and in providing a common ground on which technicians, pilots, and administrators can meet. Exact diagrams can be drawn by applying the principles of perspective, a short explanation of which is given in the next paragraph.

6.0. PRINCIPLES OF PERSPECTIVE.

Perspective is the technique of representing objects exactly as these appear to an observer at a particular point called the "station point." All ordinary perspective is based on the conception that between the observer and the object there stands a transparent plane, called the "picture plane" or "plane of projection," on which the object is projected. It is imagined that a ray of light enters the eye from each point on the

object and, on the way, pierces the picture plane. The spot where the ray from any point pierces the picture plane is the "perspective projection" of that point, and the figure obtained by joining up these spots is the perspective projection of the object. The line from the observer's eye perpendicular to the picture plane is called the "axis of perspective," and the spot where this axis pierces the picture plane is called the "centre of perspective." The distance of the station point from the picture plane, measured along the perspective axis, is called the "perspective distance." A photographic print is a perspective projection, because the image is identical with the figure which would be obtained if the station point were at the optical centre of the lens, and if the object were projected on to a picture plane located at a perspective distance equal to the focal length, and arranged so that the axis of perspective coincides with the optical axis.

In making a perspective diagram, the picture plane is conventionally taken as vertical, and the object to be represented is taken as resting on a horizontal plane called the "ground plane." The horizontal plane through the observer's eye is called the "horizon plane," and its intersection with the picture plane is called the "horizon." These terms are illustrated in Fig. 7, which shows the construction of a perspective projection for the line AB lying in the ground plane, and viewed from a point E located at a distance w to the left of AB, and at a distance h above the ground plane. In this figure, the picture plane has been taken perpendicular to AB, and it should be noted that in this case, the projection, *ab*, when produced, passes through the centre of perspective.

This is a particular case of the general proposition that the projections of any system of parallel lines all converge to a point, and that if the lines lie in planes parallel to the ground plane, then the point of convergence is on the horizon. This point is known as the "vanishing point" of the system and in general is to be found by drawing the ray from the eye in the direction of the system, and finding where this ray pierces the picture plane. The vanishing points are of fundamental importance when making perspective projections. In Fig. 7, attention is particularly drawn to the fact that the angle θ which the line *ab* makes with the vertical is $\tan^{-1} w/h$. This angle, for convenience, may be called the "perspective angle" of the line AB.

The making of perspective diagrams is facilitated by the use of plotting webs such as that shown on Fig. 8. This gives the perspective projections of various systems of lines lying in the ground plane, as explained in the notes at the right hand side of the diagram. When the diagrams are made, they must be looked at with one eye closed and with the other eye at a perpendicular distance from the diagram equal to the perspective distance. Otherwise they may appear to be distorted, particularly if the perspective distance is less than 10 inches.

7.0. FIELD OF VIEW OF PILOT.

In the study of the visual aids, a perspective diagram is of little use until a line is added to it showing the downward limit of the pilot's field of view. This is easily obtained for any particular type of aircraft by setting up a camera in the cockpit and taking two photographs, one in the position of the pilot's left eye, when his head is on the left, and the other in the position of the pilot's right eye, when his head is on the right. From these photographs, a cut-off line can then be selected which is representative of the particular type of aircraft. Fig. 9 shows one such photograph which was taken for the purpose of recording the view when taxi-ing. A pinhole camera was used because a wide angle can be covered by this means, the lack of definition being no disadvantage for this purpose.

The method used by the writer for taking these photographs is to have the aircraft standing on the apron or at the end of a runway, pointing along it as if about to take off. The camera is then set up in the cockpit with the optical axis horizontal and pointing straight ahead. (This can often be done with sufficient accuracy by eye.) An observer then goes to the tail of the aircraft and takes a sight on the horizon in the vertical plane through the longitudinal axis of the aircraft. This point will be the centre of perspective of the photograph and it can either be marked with a distant pole, or the aircraft can be turned until the point coincides with some landmark on the horizon, which can later be identified on the photograph. After the photograph has been taken it is enlarged until

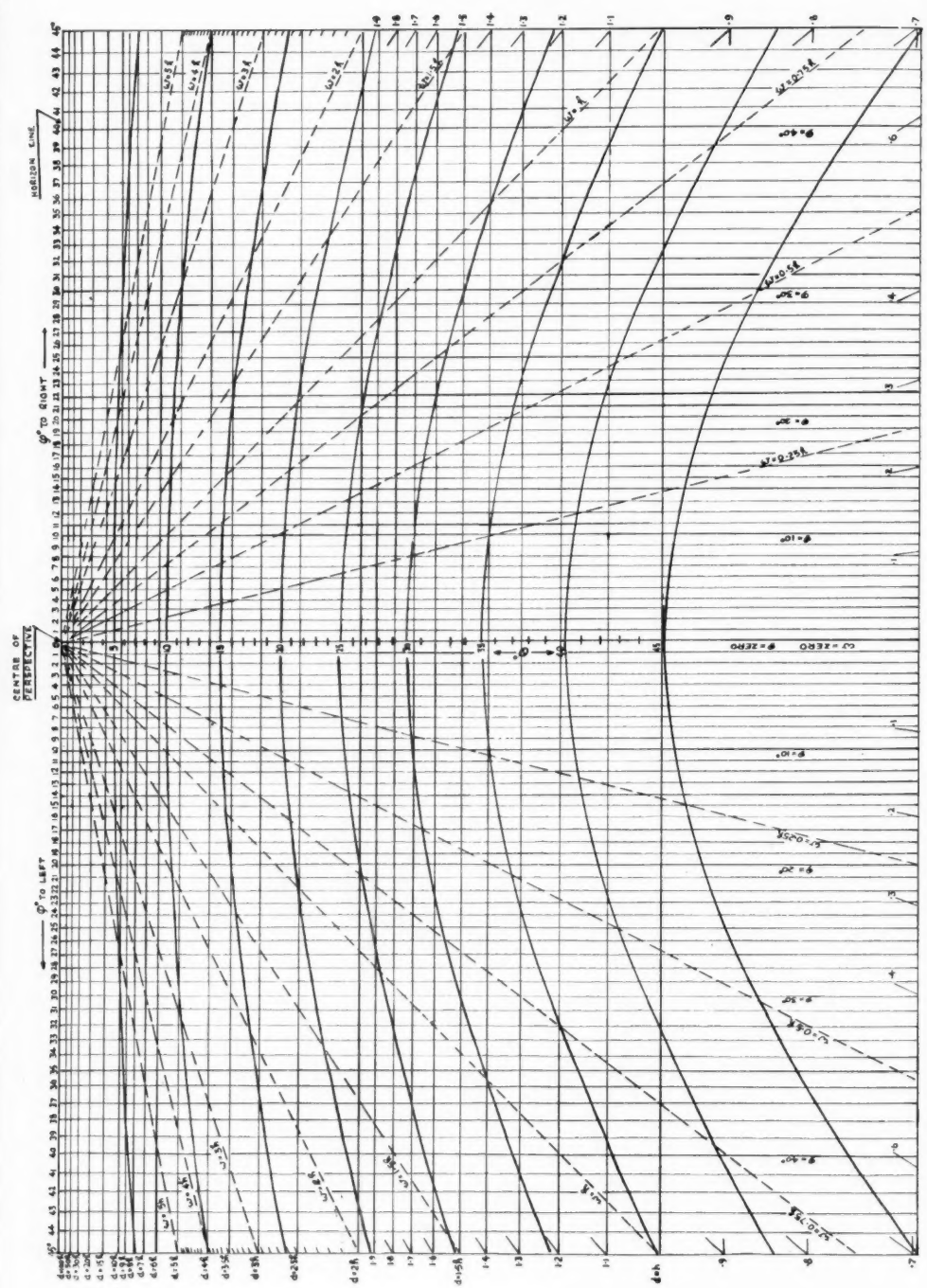


Fig. 8.
Perspective plotting web.

Explanatory Notes.

This web is a perspective projection of an imaginary system of lines lying in a plane perpendicular to the plane of projection. The perspective distance, i.e., the distance of the observer's eye from the plane of projection is 10". All angles are measured from the observer's eye, and all distances are in terms of the distance of the observer from the plane in which these imaginary lines lie.

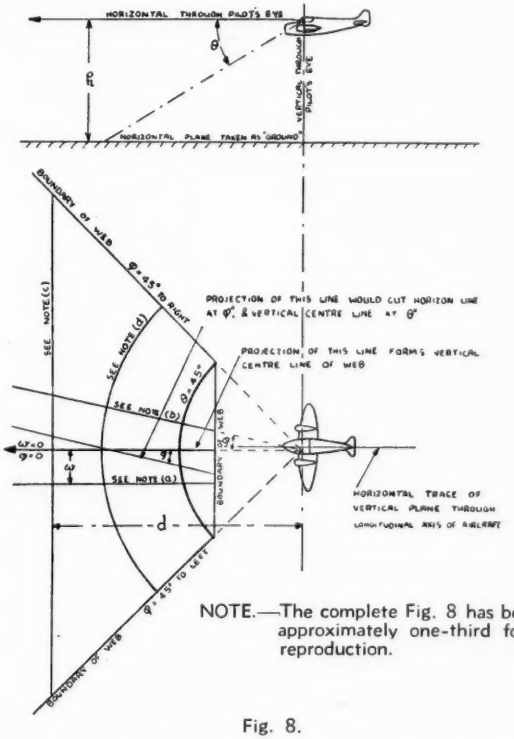
The diagrams below show the application to the case of an aircraft. In this case the "observer" is the pilot, and the imaginary lines are supposed to be marked on the ground, which is taken to be flat. The ground is also taken to be horizontal, from which it follows that the plane of projection is always vertical. The plane of projection is also taken to be perpendicular to the vertical plane through the longitudinal axis of the aircraft. With these conventions, the relationships between the lines on the ground and the lines on the web are as follows:—

(a) Straight lines on the ground parallel to the vertical plane through the longitudinal axis of the aircraft project into straight lines radiating from the centre of perspective. The projected lines are shown dotted for various values of the ratio w/h, w and h being defined in plan and elevation shown below.

(b) Straight lines on the ground radiating from a point vertically below the pilot's eye project into vertical straight lines. The projected lines are marked off along the horizon line at intervals of 1°.

(c) Straight lines on the ground perpendicular to the vertical plane through the longitudinal axis of the aircraft project into horizontal straight lines. The projected lines are drawn for various values of d/h, d being defined in the plan shown below.

(d) Circles on the ground having as their centre a point vertically below the pilot's eye, project into hyperbolas. These hyperbolas, which are drawn at intervals of 5°, represent lines of constant angular depression below the horizontal, or of constant range measured from the pilot's eye.


HORIZONTAL THROUGH PILOT'S EYE
θ
h
VERTICAL THROUGH PILOT'S EYE
HORIZONTAL PLANE TAKEN AS "GROUND"
BOUNDARY OF WEB
φ = 45° TO RIGHT
PROJECTION OF THIS LINE WOULD CUT HORIZON LINE AT φ° & VERTICAL CENTRE LINE AT θ°
PROJECTION OF THIS LINE FORMS VERTICAL CENTRE LINE OF WEB
SEE NOTE (c)
SEE NOTE (d)
SEE NOTE (b)
SEE NOTE (a)
φ = 45°
ω = 0
φ = 0
ω
φ°
BOUNDARY OF WEB
HORIZONTAL TRACE OF VERTICAL PLANE THROUGH LONGITUDINAL AXIS OF AIRCRAFT
d
φ = 45° TO LEFT
BOUNDARY OF WEB

NOTE.—The complete Fig. 8 has been reduced to approximately one-third for purposes of reproduction.

Fig. 8.

Perspective plotting web.

[Changes in attitude typical of civil aircraft (see opposite).]

If attitude in 2½° glide (flaps down) is taken as datum, then on checking back before touch down, the nose comes up above datum by about 4°. The attitude after the main wheels touch ground depends on the type of undercarriage. With a nose wheel, the nose comes up a further 2° immediately after touch, but shortly afterwards drops by about 7°, at which point the nose wheel touches the ground. The taxi-ing attitude with a nose wheel is therefore about 1° below datum. With a tail wheel the change in attitude after touch is all in the nose-up direction, and is about 4°, at which point the tail wheel touches the ground. The taxi-ing attitude with a tail wheel is therefore about 8° above datum, which is about 9° higher than for a similar aircraft with a nose wheel.

Fig. 8.
Perspective plotting web.

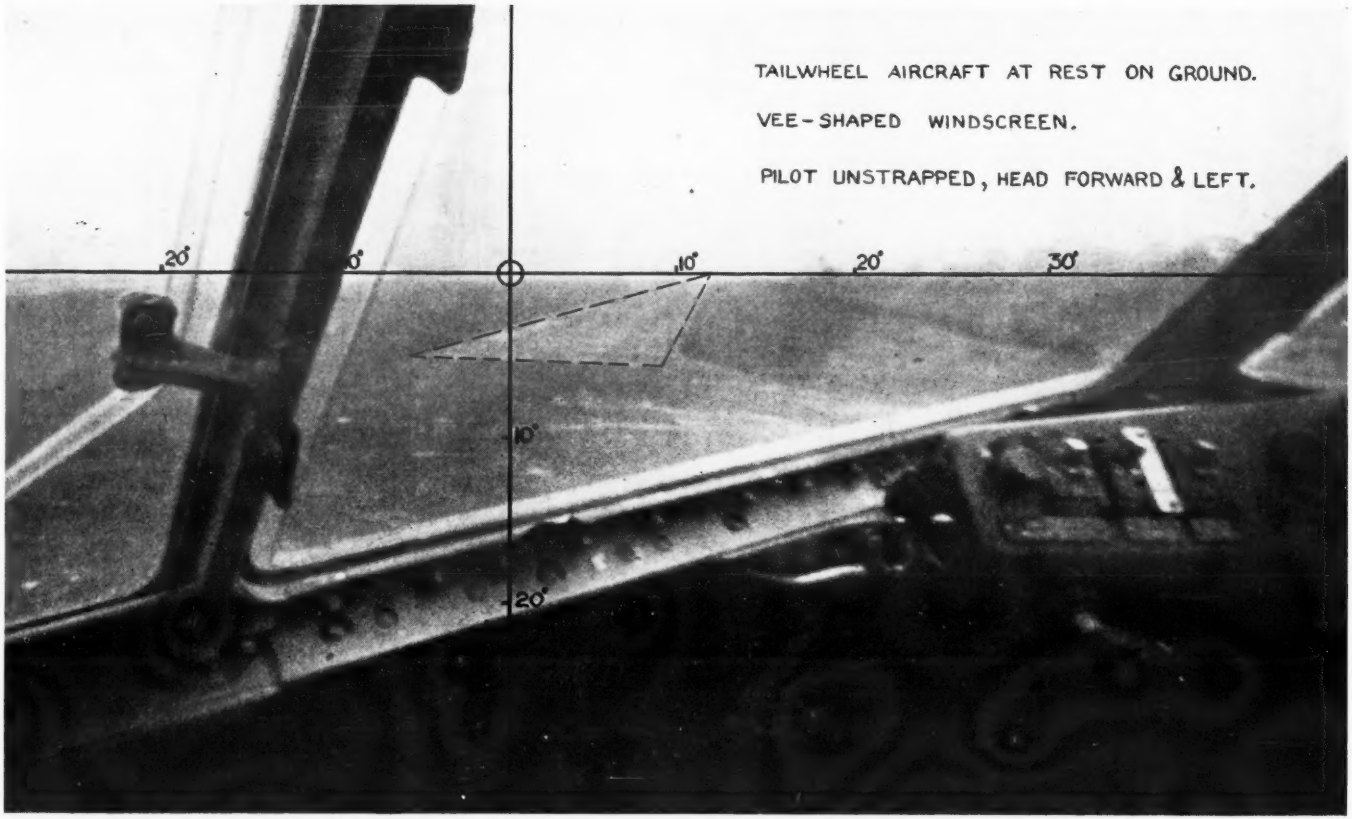

TAILWHEEL AIRCRAFT AT REST ON GROUND.
VEE-SHAPED WINDSCREEN.
PILOT UNSTRAPPED, HEAD FORWARD & LEFT.
20°
0°
10°
20°
30°
10°
20°

Fig. 9.

the equivalent focal length is equal to whatever perspective distance is required. The horizon and centre of perspective are then marked on the print. If there is a runway in the field of view, the horizon can be obtained by finding the point of convergence of the sides, as has been done in Fig. 9.

It has been found that a pilot who is securely strapped in, and whose attention is fully engaged in reading instruments and operating the controls, tends to keep his head in a fixed position. The coaming in the cockpit therefore acts as a rough sighting device, enabling the pilot to judge the height of the aircraft by means of the angle subtended by objects on the ground whose real size is known to him. By making use of this fact, it becomes possible to devise a pattern for the approach lights which will enable a pilot who only sees a small amount of the total pattern to know whether he is over-shooting or under-shooting the runway. In order to understand how this can be done, it is necessary to examine the exact behaviour of the pattern which is significant for judging the approach, *i.e* that formed by the three elements, the runway, the horizon, and the frame formed by the edges of the windscreen.

Fig. 9.

8.0. BEHAVIOUR OF RUNWAY AND HORIZON AS SEEN BY PILOT MAKING A DAYLIGHT APPROACH.

Let us consider an aircraft approaching the end of a runway at an angle α as shown in Fig. 10, and make perspective projections of the runway on a vertical picture plane arranged at right angles to the vertical plane of symmetry of the aircraft. The frame formed by the edges of the windscreen, for the purposes of the discussion immediately following, can be conveniently represented by a single straight line fixed with reference to the structure of the aircraft and, in order to fix our ideas, we may imagine that this line is produced by an optical sighting device which projects on to the picture plane a line parallel to the vertical plane of symmetry of the aircraft. Then the pattern seen by the pilot when the aircraft is at point A on the centre line of the runway, and is heading correctly, is shown in Fig. 11.

If the pilot now operates the controls so that the aircraft makes a flat turn of $\delta°$ to the left, he will see the runway move laterally to the right of the fixed sighting line, as shown in Fig. 12. In addition, the apparent shape of the runway will change very slightly, in that the short sides of the rectangle, when produced far enough, meet on the horizon. These short sides are tangential to two of the family of hyperbolae shown in Fig. 8 at the points where these hyperbolae intersect the vertical line $Q=\delta$. It follows that these sides remain nearly parallel to the horizon unless δ is very large.

Now imagine that there are lines on the ground parallel to the runway and extending in front of the aircraft to infinity. When the aircraft is at A, these lines would appear to the pilot to radiate from the point H, where the fixed sighting line cuts the horizon, as shown in Fig. 13. If the aircraft is flying on the correct compass course, but is laterally displaced to point B on the line marked "5," then the pattern seen by the pilot will be as shown in Fig. 14; that is, it will appear to have rotated round H. In this case the apparent shape of the runway will have changed considerably. It should be noted that the short edges of the rectangle still appear to be horizontal.

Now if we again suppose the aircraft to be at A, but to be banked instead of level, then the five lines shown in Fig. 13, together with the horizon, will appear to have rotated about the point where the axis of roll intersects the ground. Since this point is close to H, it follows that *if the horizon were missing*, the pilot would be unable to decide from the ground indications whether the aircraft was banked or laterally displaced. He can, of course, find out what is happening by waiting for two or three seconds and watching what further changes take place in the pattern, or by looking at his instruments. The danger is that the visual impression initially received may be so strong that he instinctively acts upon it without waiting, in which case the outer world may behave in a way he does not expect, and so cause feelings of confusion.

While not wishing to dogmatise in such a complicated matter, the author would suggest that this effect may be one of the causes of the momentary vertigo which sometimes occurs when a pilot goes over from instruments to visual. However this may be, it certainly explains such effects as the apparent

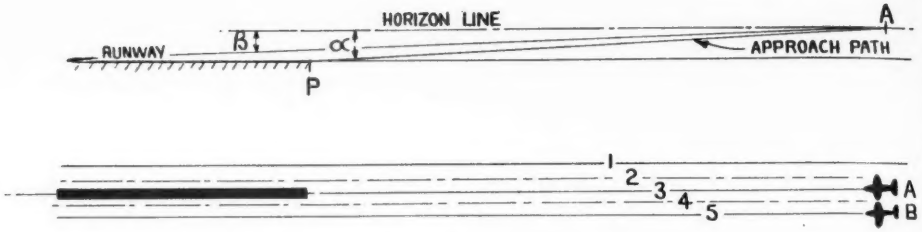


Fig. 10.
Plan and elevation showing aircraft approaching runway.

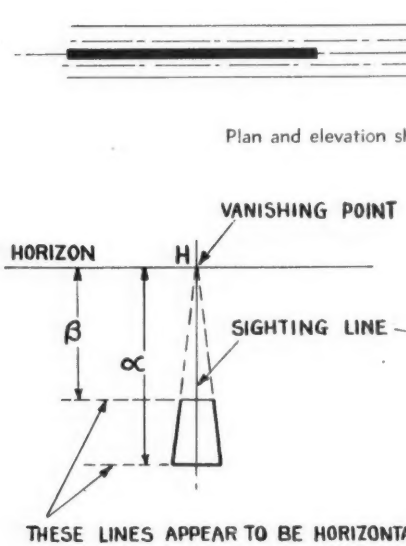


Fig. 11.
View from position A. Correct heading.

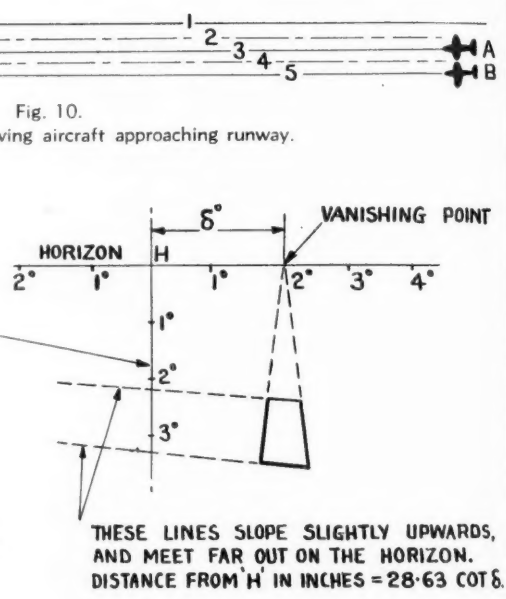


Fig. 12.
View from position A. Aircraft heading δ° to left.

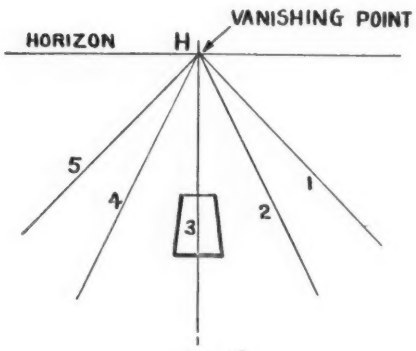


Fig. 13.
View from position A. Correct heading.

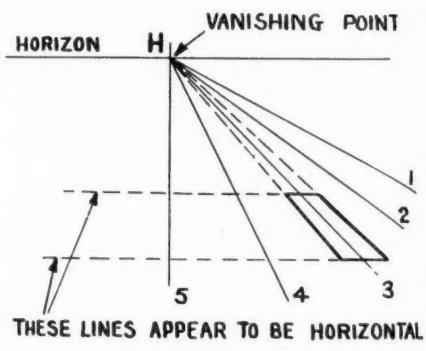


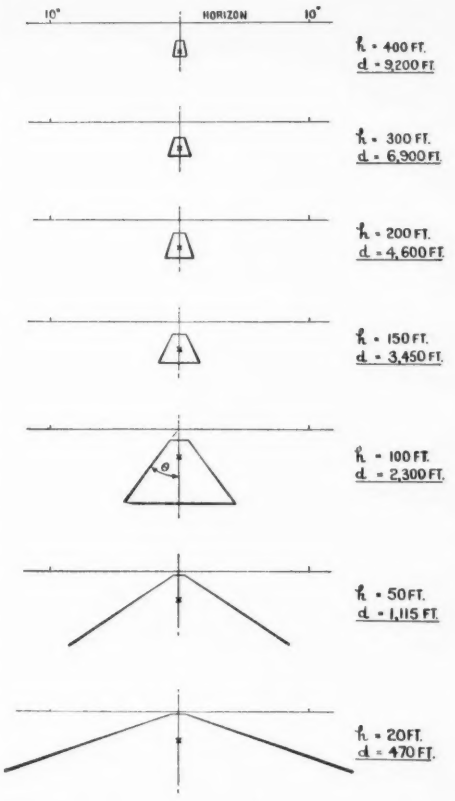
Fig. 14.
View from position B. Correct heading.

Figs. 10-14.
Diagrams showing appearance of runway for various errors of alignment.
Aircraft level in all cases.

swinging of the runway, and the difficulty of following lines of lights in conditions of bad visibility.

It should also be noted that if the visibility is poor and the aircraft makes a banked turn in order to correct a lateral error, then the error will at first appear to increase, because the farther end of the runway and the point round which it rotates will not be visible. This effect is always present, but its extent may not be appreciated by pilots unaccustomed to bad weather flying, because in good visibility attention is fixed on the vanishing point, and this moves very little, if at all, when the aircraft banks. This effect is also illustrated in Fig. 21.

In addition to lining up on the runway, the pilot has to adjust his height so that he will touch down at the right point. If we imagine that the glide path intersects the runway at a point X instead of at P, X being 1,000 ft. from the threshold, then the successive views seen by a pilot approaching vertically over the centre line at an angle of $2\frac{1}{2}°$ are shown in Fig. 15. In these views, X is always $2\frac{1}{2}°$ below the horizon, and the pilot's task is to operate his controls so as to keep it there until he wishes to flatten out. Since the tangent of the perspective angle θ (see also Fig. 7), is half the width of the runway divided by the height of the observer, the pilot gets an idea of his height by observing the value of θ, and an idea of his rate of descent by observing the rate of increase of θ. For instance, if the angle between the edges of the runway appears in perspective to be 90°, then θ is 45°, and the pilot's head is at a height equal to half the width of the runway. When the aircraft comes close to the ground, the texture of the foreground can be observed and this provides an extra, and probably more accurate, clue to the height.



Note:—
h = height of pilot's head above level of runway.
d = horizontal distance from pilot's head to point X where glide path intersects runway.
Angle of glide = $2\frac{1}{2}°$ Width of runway = 150 ft.

Fig. 15.

Successive views of runway as seen by pilot approaching down centre line, without bank.

9.0. TYPE OF PATTERN RECOMMENDED FOR HIGH INTENSITY APPROACH LIGHTS.

On a modern airport the contrast between the runway and the rest of the surface is often small, and the surface itself may have little texture. Daytime mist first reduces what contrast and texture there is and, as it gets worse, finally blots out the whole horizon and all the vanishing points associated with it, so that the pilot is left with only the lights for making his visual judgments. It follows from the previous paragraph that the approach light pattern must, as a first necessity, supply the equivalent of a horizon, and it also follows that this can be done by means of bars of lights running transversely across the extended centre line of the runway. It is also clear that patterns whose directional indications are derived from vanishing points, *i.e.* parallel lines, vees, and funnels, are to be deprecated, because as visibility gets worse, less and less of the pattern is seen and mental

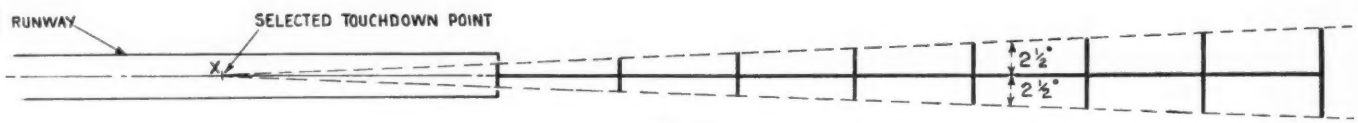


Fig. 16.
Schematic diagram showing type of pattern proposed for high intensity approach lights.

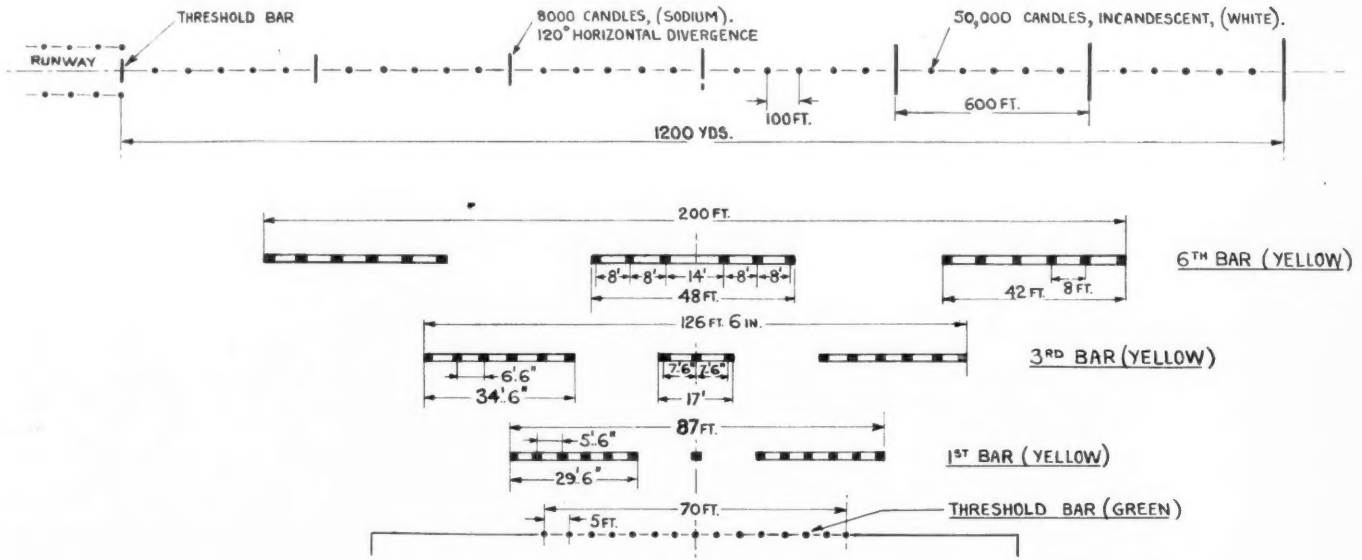


Fig. 17.
System installed at Farnborough for flight tests

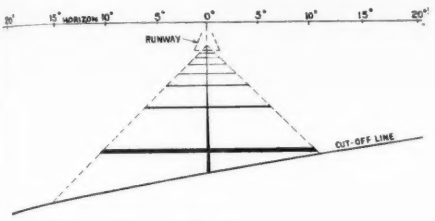


Fig. 18.

Pattern seen from station point vertically over CL. Correct heading. No bank.

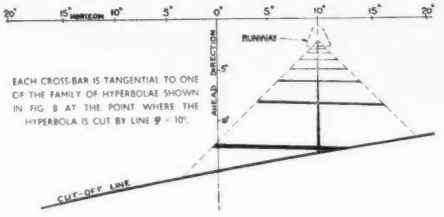

20° 15° HORIZON 10° 5° 0° 5° 10° 15° 20°
RUNWAY
EACH CROSS-BAR IS TANGENTIAL TO ONE OF THE FAMILY OF HYPERBOLAE SHOWN IN FIG. 8 AT THE POINT WHERE THE HYPERBOLA IS CUT BY LINE ψ = 10°.
AHEAD DIRECTION
5°
10°
CUT-OFF LINE

Fig. 19.

Pattern seen from station point vertically over CL. Heading 10° to left. No bank.

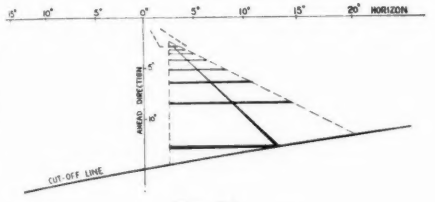


Fig. 20.

Pattern seen from station point to left of CL. Lateral error equal to height. Aircraft heading parallel to runway. No bank.

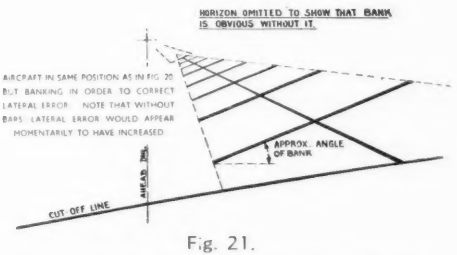

HORIZON OMITTED TO SHOW THAT BANK IS OBVIOUS WITHOUT IT.
AIRCRAFT IN SAME POSITION AS IN FIG. 20 BUT BANKING IN ORDER TO CORRECT LATERAL ERROR. NOTE THAT WITHOUT BARS, LATERAL ERROR WOULD APPEAR MOMENTARILY TO HAVE INCREASED.
APPROX. ANGLE OF BANK
AHEAD DIR.
CUT OFF LINE

Fig. 21.

Pattern seen from station point to left of CL. Lateral error equal to height. 20° bank, right wing down. Aircraft still heading parallel to runway.

calculations as to where the vanishing point would be if it could be seen, get progressively more difficult. (In the case of wide vees, say 6° or more, it is even possible in certain circumstances for an observer to get a momentary impression that the direction of the system is at right angles to its actual direction.)

For this and other reasons which will subsequently appear, the author has come to the conclusion that the directional indication is best provided by a single line of lights located along the extended centre line of the runway. The type of pattern recommended therefore, consists of a centre line of lights with bars of lights arranged at intervals across it.

Pilots would probably all agree that they could fly level over a pattern consisting of a line with crossbars of equal length, since all they would have to do would be to fly so that successive bars subtended the same angle as they disappeared underneath the nose, and this would be little different from flying level over a runway. Therefore, it is reasonable to suppose that if pilots were presented with a pattern such as that shown in Fig. 16, and were asked to fly so as to keep successive bars of equal apparent width, they would also be able to do so. This would mean that they were flying down a path which intersected the centre line at the point X. In other words, there is good reason to believe that a pattern such as that shown on Fig. 16 provides a visual glide path from the point where it is picked up to the point X. If successive bars appear gradually to increase in width as they disappear underneath the nose, then the aircraft is under-shooting the point X, and if they appear to decrease in width, the aircraft is over-shooting point X. It should be particularly noted that the pilot is not tied to a particular glide path fixed in space and that in all cases, he is brought down from wherever he happens to be to the point X.

Because the type of pattern shown in Fig. 16 gives indications of alignment, bank, and glide path, in a manner which is free from ambiguity even when only a small portion of the whole pattern is seen, the author submits that some pattern on this principle will ultimately provide a solution which will be

Fig. 17. System installed at Farnborough for flight tests

generally accepted. In Fig. 16 the angle subtended by the bars at the point of origin is 5°, but it is probably not essential to use so large an angle as this.

Figure 17 shows the actual pattern which is now installed at Farnborough aerodrome for flight tests, and it will be seen that this is based on an angle of $2\frac{1}{2}°$, which the author regards as about the minimum. It will also be noted that the bars have been broken up into three segments so as to save wayleaves and fittings, and also to permit the bars to be coded for the purpose of giving direct indications of range. These range indications can be given in many other ways, as for instance, by coding the centre line.

As this pattern is easily distinguishable from street lighting patterns it is not essential to use colour. However, it is proposed to use sodium lights for the bars firstly, because of their high efficiency and secondly, because their large size and yellow colour will give texture to the pattern and make it instantly recognisable, even with extraneous lighting. For the centre line lights, it is proposed to use white incandescent lights having a maximum intensity of at least 50,000 candles, which is about 25 times as bright as any street lighting fittings seen from the air. Both types of light are of simple construction, and are now coming off production as required.

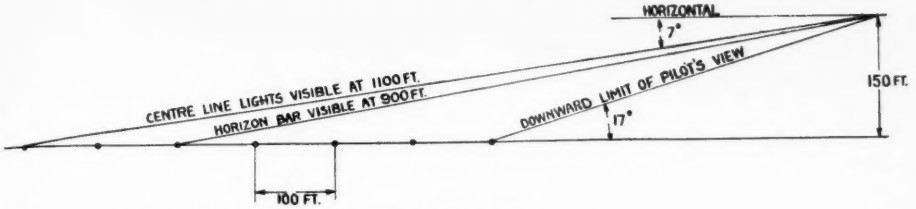
It is an instructive exercise in perspective to make perspective diagrams showing the appearance of these patterns in various situations. The plotting web shown in Fig. 8 enables this to be done quite easily, but on a first trial a little difficulty will probably be found in remembering that lines which are parallel, in reality converge in perspective and that lines which diverge from the station point are parallel in perspective. Figs. 18 to 21 are diagrams showing how the pattern shown in Fig. 16 appears in perspective in the situations indicated on the diagrams. These diagrams show the whole approach system, but it should always be remembered that in really bad conditions, only one or two bars will be seen.

10.0. VISIBILITY IN WHICH BAR PATTERNS CEASE TO BE USABLE.

As the ranges at which the lights are seen are small, the limit of usefulness of this system will depend on the downward view which the nose of the aircraft permits the pilot to have. The information available to

Fig. 22.

Curves showing ranges at which a light source will produce illuminations of 1.5 mile candles (night) and 1,000 mile candles (day).



Horizon bars—sodium lights of 8,000 candles.
Centre line lights—white incandescent lights of 50,000 candles.
100 ft. between centre line lights. 600 ft. between horizon bars.

Fig. 23.
Diagram showing number of lights seen by pilot in fog densities corresponding to meteorological visibilities of 100 yards at night and 200 yards by day.

the writer suggests that on new types of aircraft the downward view in the ahead direction will be 15° below the horizontal when the aircraft is flying level at normal cruising speed. This means a downward view of about 17° when the aircraft is making an approach. Not all types of aircraft will have as good a view as this, but this simply means that the aircraft with poor views will be less safe in bad weather than aircraft with better views.

The visual aids will be less effective in daytime than at night because of the increased brightness of the background. If we consider the performance of the approach lights in two densities of fog, *i.e.* a meteorological visibility of 100 yards at night and 200 yards by day, we find that the ranges obtained are much the same, since reduction in fog density about compensates for the increase in the brightness of the background. Fig. 22 shows that under these conditions the range of the centre line lights is about 360 yards and that of the bars about 300 yards. As may be seen from Fig. 23, this means that an aircraft with a downward view of 17° would see about six lights ahead when the height of the pilot's head was 150 ft. and that, except for a very short period, one bar would always be in view to give the pilot a check on his attitude and rate of descent. This seems to the author to be about the limit of usefulness of this system.

The curves shown on Fig. 22 assume the fog to be equally dense at all heights. Actually, the principal type of fog which affects inland airfields at low level is "radiation fog," that is, fog produced by the cooling of the ground by outgoing long wave radiation. The upward growth of this type of fog may be of the order of one foot per minute, and it is quite likely that for most of its duration the slant transmission will be more than that measured along the ground. It may therefore turn out that the performance of the approach lights will be better than that given above, and it may even be possible to cope with quite dense fogs merely by using a little F.I.D.O. at the threshold of the runway in conjunction with suitable day markings.

One question which is often raised is whether or not fog will blur the sharp outline of the bars in the same way as the bulb of an opal lamp blurs the outline of the light source. The answer is that some opal glasses do not blur the outline of the source, depending on the ratio of the diameter of the diffusing particles to the wavelength of the light. Anyone can satisfy himself by observing the sun in cloud, or street lamps in fog, that the sharp outline of the light source is not, in fact, blurred. This has also been demonstrated directly by observations on the bar pattern from a captive balloon, and there are now quite a number of observers who can confirm that the bars appear with clear-cut outlines, both by day and by night, in all atmospheric conditions in which they have been observed. It may be mentioned, however, that a glow surrounds the fittings in night fog. In day fog no such glow is visible but the colour of the farther sodiums appears to be whiter than the colour of those closer to the observer. This happens to all coloured objects in fog and is caused by light scattered by the fog particles mixing with the light coming direct from the fittings.

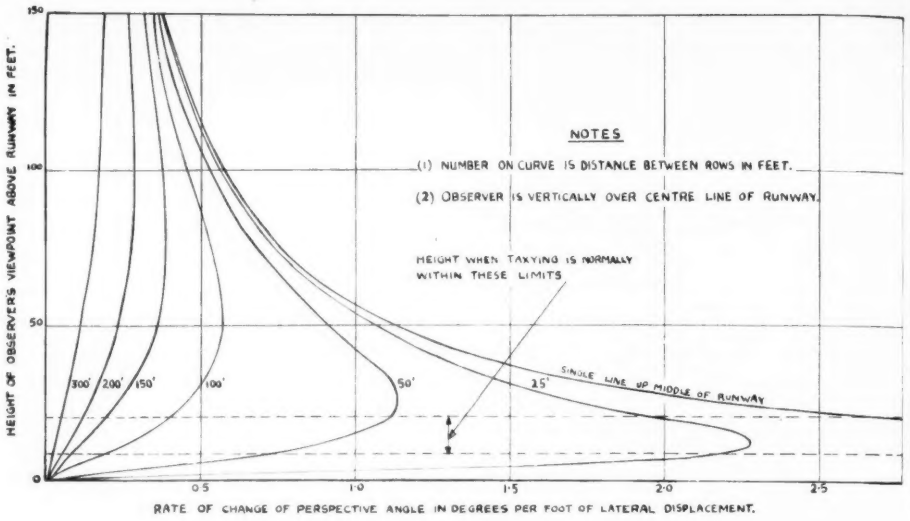


Fig. 24.

Curves showing the accuracy with which lateral displacement can be judged from parallel rows of runway lights for various spacings between rows.

Another question often raised is that of dazzle. The answer to this is that with the intensities under consideration, *i.e.* 5,000 candles for the runway lights, and 50,000 to 100,000 candles for the centre line approach lights, no trouble is experienced in daylight. At night, the runway and centre line lights will be dimmed to suit the atmospheric conditions. In the worst conditions, the lights will not be dimmed, but in these cases it should be remembered that the pilot will be landing on his light patterns, and not by observing the texture of the foreground. The question of dazzle, therefore, is reduced to whether or not the lights produce discomfort glare or prevent the pilot from reading his instruments. Flight tests are now being made to decide what intensities can be used safely.

11.0. RUNWAY LIGHTING PATTERNS.

If the pilot has been able to use the approach aids successfully, the aircraft should arrive over the threshold of the runway at a height such that the pilot's head is about 50 ft. above the ground. After the end of the runway has been crossed, the pilot has no further need to relate his height to any particular point of touch down, and a pattern which indicates direction, height, and lateral displacement, is sufficient. A pair of parallel lines indicate direction by means of their vanishing point, and also indicate height and lateral displacement by means of changes in the perspective angle θ, as explained above.

Now the rates of change of θ with respect to w, the distance of the observer from the particular line, and with respect to h, the height of the observer above the plane of the lines, are obtained as follows:—

$$\theta = \tan^{-1} w/h$$

$\therefore (d\theta)/(dw) = h/(w^2 + h^2)$, giving the family of curves shown on Fig. 24,

and $(d\theta)/(dh) = w/(w^2 + h^2)$, giving the family of curves shown on Fig. 25.

If it were true that changes in θ can be appreciated equally at all values θ, then these curves would show the accuracy with which judgments of lateral displacement and height can be made from a pair of parallel lines. However, it is probable that smaller changes can be appreciated near the vertical and horizontal, that is, when θ is near zero or near 90°, than at angles in between, so that where the variations in θ are large, it is necessary to regard these curves as giving only the

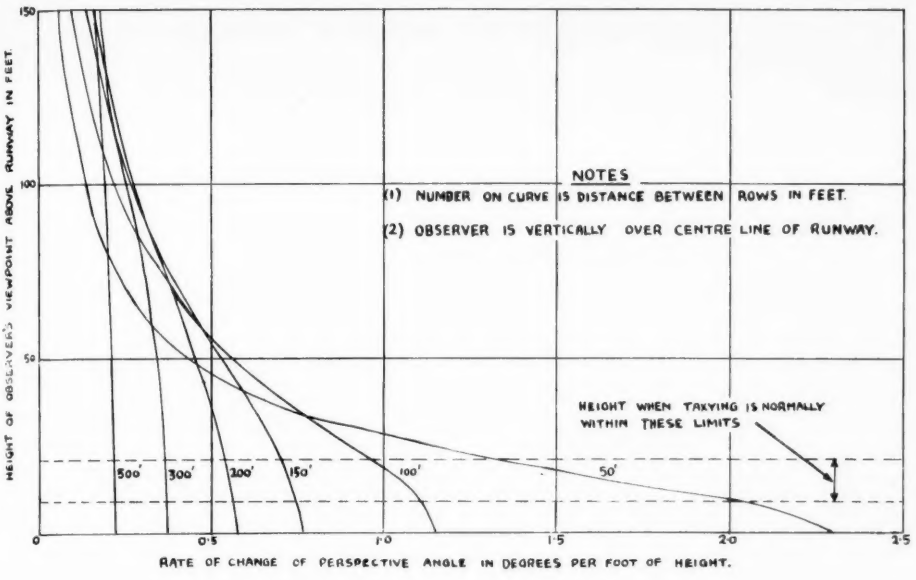


Fig. 25.

Curves showing the accuracy with which height can be judged from parallel rows of runway lights for various spacings between rows.

approximate relative accuracy of these judgments.

It will be noted that when w is large compared with h, the indication of lateral displacement is proportional to h/w^2, from which it follows that a small aircraft taxi-ing up the middle of a wide runway without day markings has a very poor indication of its lateral displacement. By far the best indication of this is given by a single line up the middle and for this and other reasons, it would be advantageous to continue the centre line of the approach system for some distance up the runway so as to enable pilots to detect incipient swing. About 2,000 ft. from the threshold has been suggested for this, but practical considerations will probably prevent this suggestion from being adopted.

12.0. SCALE EFFECTS IN RUNWAY LIGHTING PATTERNS.

A pilot is only able to judge his height from a pair of parallel lines provided that he is familiar with the scale of the pattern. For instance, if in country A, the distance between the rows is 200 ft., and the distance between lights 100 ft., and if in country B, the corresponding distances are 150 ft. and 75 ft., then the runway in country B is a scale model of that in country A, the scale being one to 0.75. The runway pattern in country A, seen from any height h will therefore be identical with the pattern seen in country B from a height of $0.75h$. It follows that unless the pilot can remember which pattern he is landing on, his judgment of height may be in error by $0.25h$, unless the visibility conditions are such as to enable him to correct his judgment by observation of the texture of the foreground.

The importance of keeping the distance between the rows of runway lights constant has always been realised in this country, and this distance was maintained at 150 ft. at those airfields recently built in which the width of the runways has been increased to 300 ft. This decision was far-reaching, because it carried with it the implication that flush-type runway lights would have to be

used and, as is well known, very high intensities cannot be obtained from this type of light.

Experimental work done in 1943 demonstrated that an intensity of 5,000 candles could be obtained from flush-type fittings and, as this is of the same order as the intensity of the sodium flares, it was agreed that this would be acceptable. The writer is convinced that the proper place for high intensities is in the approach, and not on the runway, and that experience on the new aids will justify the use of flush-type lights.

This view is at variance with opinion in America, where the practice is to use elevated type lights located 10 ft. out from the edge of the runway, irrespective of its width. If the distance between rows cannot be standardised internationally, then it may be necessary to select some scale-fixing pattern, internationally agreed as regards dimensions, and add this to the normal runway pattern for a certain distance on each side of the normal touch down point. These scale effects, provided that they are not too large, are only important in fog, and it is likely therefore that scale-fixing patterns will only be required on instrument runways.

13.0. TAXIWAY LIGHTING PATTERNS

In the case of large civil airports, it is quite possible that taxi-ing and ground movement control may prove to be the factors which limit the traffic capacity of the airport, and therefore it is of great importance to be able to taxi as quickly as possible on both runways and taxiways in all conditions of visibility. The author understands that a practical radio solution to the taxi-ing problem presents considerable technical difficulties, apart from the political difficulties of getting it adopted, and it is fortunate therefore that the visual solution is both simple and cheap.

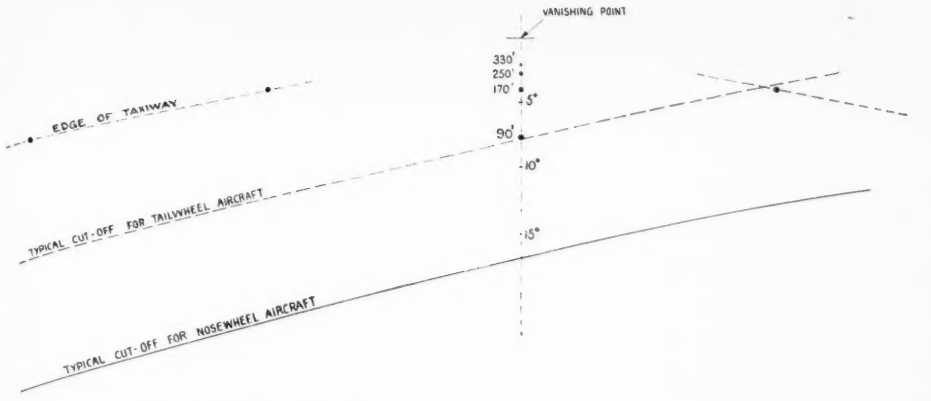
Most existing airfields in this country have three runways, the ends of which open on to a perimeter track 50 ft. wide. Since the airfield forms a single island inside this track, and the track itself is narrow, it is a simple matter to provide satisfactory taxi-ing aids by outlining the tracks with lights, using one colour, yellow, for the outside and another colour, blue, for the inside. The new civil airports are arranged on a very different plan, the terminal buildings and parking concourse being in the middle, with the runways outside. The taxiways are wider, 120 ft. for London Airport, and have a larger proportion of curves to straights, and the movement area includes large featureless areas of concrete which may be traversed by as many as a dozen different routes.

As soon as the method of perspective analysis was applied to the problem of taxi-ing on these airports, it became clear that merely outlining the movement area with lights, either of one or more colours, would produce clumps of lights which could only be interpreted in clear weather with great difficulty, if at all, and which, in bad visibility, would be quite useless. The author suggested, early in 1946, that the only solution was to install the lights up the middle of the taxiway, and switch in only whatever sections were required to route each particular aircraft.

After considerable discussion, it has now been agreed to adopt the centre line arrangement for London Airport, but, in addition, to outline the movement area with lights of a lower intensity and different colour. It is probable that the centre line lights will be green in order to distinguish them from runway lights, this being particularly desirable where two taxiways are parallel and close together. The lights at the edge will probably be blue.

With the centre line arrangement, the pilot always has a definite aiming point and confusion of patterns is reduced to a minimum by the reduction in the angular separation between adjacent lights. It should also be noted that when taxi-ing round a circular curve on which the lights are equally spaced, all the lights except those very close to the aircraft, appear to the pilot to have the same angular separation, this angle being half that which the distance between adjacent lights subtends at the centre of the curve. The pilot therefore knows where to look for the next light and has less difficulty in sorting out the pattern.

In good visibility the pilot will probably taxi with his head directly over the line of lights, but in poor visibility he will probably move over to the right of the line by a distance equal to about half the height of his viewpoint above the ground, that is, by a distance of between 5 and 10 ft. This does not mean that taxiways with centre line light-



Distance between lights—80 ft.
Intensity—30 candles for CL lights; 3 candles for edge lights.
Meteorological visibility—200 yards.
Illumination at eye—1,000 mile candles.
Station point—12 ft. above CL of taxiway.

Fig. 26.

Perspective diagram of lights on a straight taxiway, 120 ft. wide, in daylight fog. Plane of symmetry of aircraft parallel to vertical plane through CL of taxiway.

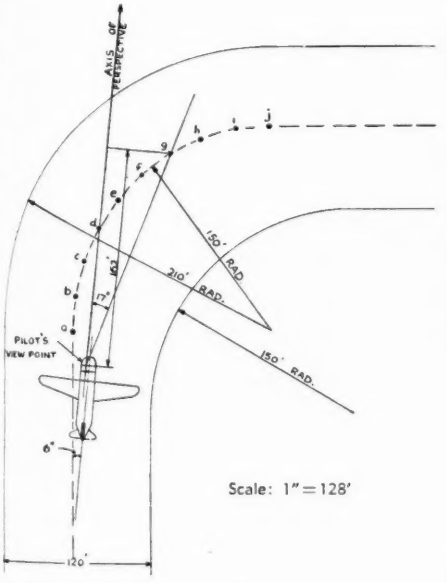


Fig. 27.

Plan view of aircraft making right turn.
(For perspective view, see Fig. 28.)

ing must be wider than those with edge lights, because the middle of a wide taxiway cannot be judged from edge lights with an accuracy better than about 10 ft.

The difficulty of making a right turn on an aircraft with a poor view to the right is not increased by centre line lighting, provided that the aircraft keeps to the right of the line of lights. As "cutting the corner" is a common occurrence in any case, it is suggested that it may be desirable to make the radius of the line of lights about the same as that of the inside edge of the bend, rather than to strike both curves from the same centre. This arrangement is shown on Fig. 27.

14.0. VISIBILITY IN WHICH CENTRE LINE TAXI-ING PATTERNS CEASE TO BE USABLE.

If we assume that an incandescent source with a life of 1,000 hours will be used, and that an all-round distribution is required in the horizontal plane, then the beam intensity before fitting the colour filters will not be more than five candles per watt. When filters are used, the beam intensities will be of the

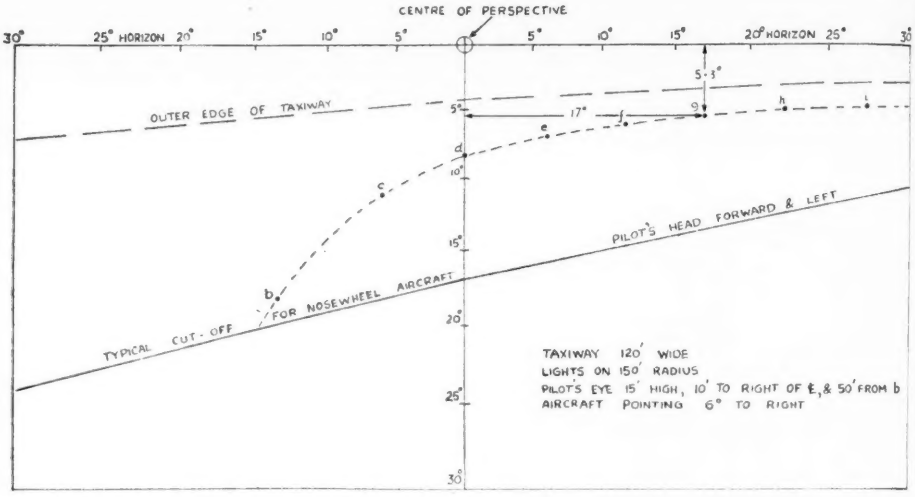


Fig. 28.

Perspective diagram of arrangement shown in Fig. 27.

order of 1.0 candles per watt for green and 0.1 for blue. Assuming 36 watt lamps in the fittings, we arrive at an intensity of about 30 candles for the centre line lights and about three candles for the edge lights. (The intensity of the taxiway lights used in Airfield Lighting Mark II was about 0.2 candles.)

In Airfield Lighting, Mark II, the distance between the taxiway lights on straight runs was 150 yards, but this was found to be far too great for bad visibility conditions and on London Airport this has been reduced to 80 ft. Fig. 26 is a perspective diagram showing how the taxiway lights on this airport will appear to the pilots of two typical aircraft, one with a tail wheel, and one with a nose wheel, in a meteorological visibility of 200 yards in daylight.

Even when the aircraft are straddling the centre line, three lights will always be in view in the first case and four lights in the second case, and rapid taxi-ing will be possible in both cases. When the visibility falls to 100 yards the number of lights seen in daylight will always be one and two respectively, and taxi-ing will still be possible, but at a reduced speed.

At London Airport the spacing which will be used on corners will be about $\frac{1}{8}$th of the radius of the bend. Fig. 27 is a plan view of an aircraft making a right turn of 150 ft. radius, and Fig. 28 is a perspective diagram showing what the pilot will see, assuming that the aircraft has a nose wheel. The light marked *i* will just be visible in daylight in a meteorological visibility of 100 yards, and here again the author submits that the indication is good enough to enable the aircraft to make the turn at a reasonable speed. If the aircraft had a tail wheel, it would have to move over to the right by about another 10 ft., but provision can be made for this by widening the track at the corner, as shown in Fig. 27. The width of the right hand portion of the track is then 70 ft., which is 20 ft. more than the total width of the tracks now in use. Any existing aircraft which can taxi on the old tracks therefore can taxi much more safely on the new tracks.

15.0. SIMULATOR FOR DEMONSTRATING THE BEHAVIOUR OF THE VISUAL AIDS.

All the theoretical work described above was completed during 1946, and was written up in three Reports issued in 1947, two in January and one in August. These were

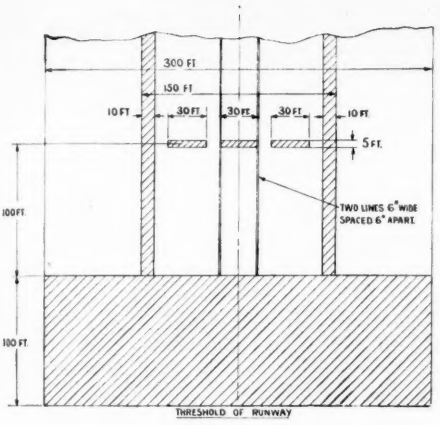


Fig. 29.

Type of day marking pattern proposed for runway. Shaded portions are white.

circulated to the member states of I.C.A.O. during the meeting of the Air and Ground Aids Division in September 1947, and aroused some interest, but it was realised that there was little hope that the results would be generally accepted unless the various patterns could be realistically demonstrated to large numbers of people in various conditions of visibility and at small cost.

The author therefore asked two of his colleagues, J. W. Sparke and H. F. Ringe, to try to build a Simulator with controls arranged as in a real aircraft, so that an observer looking into the instrument, and operating the controls, would see the patterns behave exactly as they would do in reality. Within less than three months, they had designed and built a very realistic Simulator, which has already proved to be a most useful research tool. This was completed in October 1947, and since then they have given demonstrations to about 400 people, which has meant about 8,000 simulated landings.

As regards approach light patterns, opinions have, with one exception, been strongly in favour of the bar pattern. A typical result is that after two or three runs, the subject looks up and says "I feel I can do this, although I don't know how I do it." This is exactly the reaction which was hoped for, because any system in which the pilot consciously has to "do something" is a long way behind one in which the reactions are instinctive and automatic. When approaching on the bar pattern, the subject never has any doubt as to where he is, and what his aircraft is doing, even though he may not have enough skill to come in correctly. On all other patterns there is much weaving about and general uncertainty, and the subject usually makes some remark to the effect that if he gets down on the runway, it is as much by good luck as good management.

It is obvious that this Simulator, which has now come to be known as "The Cyclorama," can be turned into an approach and landing trainer by adding throttles and instruments. Indeed, it may eventually be possible to simulate the whole landing operation,

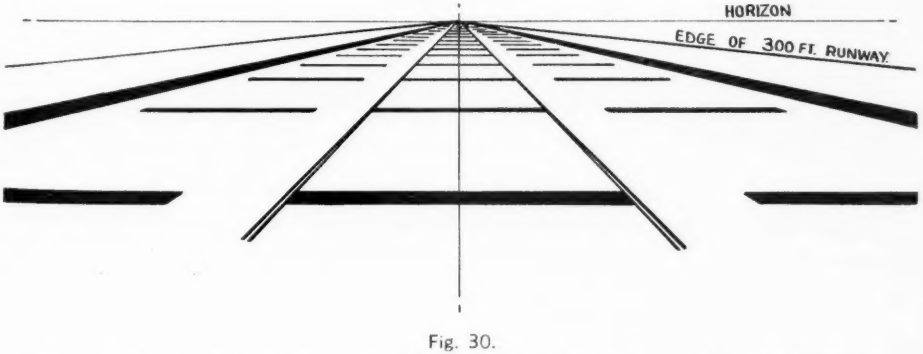


Fig. 30.

Perspective view of pattern shown in Fig. 29. Station point on centre line 15 ft. above cross bar.

including an initial approach on instruments and the final taxi-ing run to the unloading point. This could be done for any airfield and it would be possible, before a pilot left for a particular destination, to show him what he would see under conditions of bad visibility. Another advantage of the Cyclorama is that it is no longer necessary to go through the laborious process of making perspective diagrams, except as in the case of this paper, where it is desired to report the results of some investigation.

16.0. DAY MARKINGS ON THE RUNWAY.

Up to the present, day markings have not been seriously considered in this country but there is no doubt that they could be made to serve four very useful functions as follows:

(a) To increase the distance at which the runway can be picked up.

(b) To assist the pilot in making his judgments of height by accentuating the perspective angle, and by giving texture to the surface.

(c) To provide accurate guidance in the horizontal plane when the aircraft is close to the ground or taxi-ing.

(d) To remove ambiguities from the ground indications as explained in paragraph 8 above.

As regards the increase in range, no definite value can be given for this because of the variable factors mentioned in paragraph 4 and also because the result will be affected by the size of the markings. If the stripes are wide, say 10 ft. or more, then under favourable conditions the range might be doubled, as indicated by the curves A and C on Fig. 5.

The author suggests that some arrangement similar to that shown in plan on Fig. 29, and in perspective in Fig. 30, would meet the above requirements. The outer stripes would provide a perspective angle in daytime which agreed with that provided by the runway lights at night, irrespective of the width of the runway. The two double stripes up the middle of the runway have already been standardised by I.C.A.O. and should be retained, because they give texture to the runway and permit accurate judgments of lateral displacement. In very bad weather, the combination of transverse and longitudinal markings shown in Fig. 29 would remove ambiguities from the ground indications and this, together with the increased range, would greatly increase the effectiveness of F.I.D.O. It should be noted, also, that if landing lamps and taxi-ing lamps continue to be carried by aircraft, then these markings will be useful by night as well as by day.

17.0. CONCLUDING REMARKS.

It would appear from the considerations put forward in this paper that there is good ground for the belief that a landing system which integrates existing radio approach aids with properly designed high intensity visual aids, a scientific arrangement of day markings and perhaps F.I.D.O., and also utilises a training device such as the R.A.E. Cyclorama, would provide almost a complete solution to the problem of landing aircraft in bad visibility. If operational experience should prove this to be the case, then those improvements in regularity and punctuality which are so necessary to the success of airline operations would be in sight, traffic control would be simplified, and the way would be open to the more economical utilisation of airports and aircraft, particularly jet aircraft.

None of these advantages will accrue unless aircraft are built with good downward views for the pilot, and the author therefore suggests that it is a fundamental necessity that this should be specified for all civil aircraft. There is no difficulty in doing this, because the view can be conveniently specified by means of a perspective diagram and can be checked and recorded, simply and quickly, by means of a pinhole camera.

In conclusion, the author wishes to acknowledge the encouragement and helpful criticisms which he has received from many pilots, notably W/Cdr. L. E. Botting, formerly of M.C.A., but now returned to the R.A.F., Capt. H. G. Sherwood, who represents B.A.L.P.A. on the M.C.A. Airfield Lighting Committee, and more recently, Mr. A. M. A. Majendie of B.O.A.C. The author also wishes to thank his colleagues, H. N. Green, J. L. Russell and J. W. Sparke, all of whom have contributed suggestions, and generally assisted in the development of the ideas put forward in this paper.

DISCUSSION

The President: He congratulated Mr. Calvert on having presented a piece of logical reasoning in a fascinating way. He had performed for aircraft as great a service as had been performed by the man who was responsible for the provision of the reflectors along the centres of roadways.

A. M. A. Majendie (British Overseas Airways Corporation): The interpretation of visual aid patterns could be divided into two separate processes: first the presentation to the pilot's eye of a suitable complex of lights and second, the subjective utilisation by him of this information. Mr. Calvert had confined his attention to the former process, and had shown strong reasons for the employment of certain types of layout, without becoming involved in a discussion of subjective or physiological effects. Mr. Calvert was, however, the first to recognise the importance of such a discussion.

As the greater part of the matter to be reviewed rested on the perspective appearance of patterns, he would like to draw attention to a phenomenon of great importance. The optical presentation upon the retina of the human eye of a perspective pattern did not necessarily result in the same pattern being seen in the mind's eye at the conscious level. Knowledge of the real shapes and relative sizes of objects in the external world conditioned their perception of them, and they tended to see things as they thought they ought to be, and not simply as presented by the optical system of the eye. For example, the pilot's knowledge of the parallel nature of the flarepath lights, aligned along either side of a runway, produced a subjective reduction of the perspective angles as calculated by direct projection. That this effect might be very powerful had been shown by experiments in psychological laboratories. It accounted for the feeling of distrust with which many experienced pilots had greeted Mr. Calvert's perspective diagrams, where the full value of all perspective angles was shown without reduction. This distortion of the pure perspective image had been called "phenomenal regression" by Professor Thouless of Cambridge.

The factor of phenomenal regression was a quantity differing widely among different people. This variation was in itself of little significance, as each pilot would become conditioned to his own private factor of distortion under a given set of circumstances. Unfortunately, it had been shown that the extent of phenomenal regression might vary widely for a given person, and it appeared probable that the factor of distortion was considerably reduced under conditions of fatigue. In the latter case, the subjective perception would degenerate towards the true optical perspective presentation, and angles that were normally seen under conditions of subjective reduction assumed their true values. Under those circumstances small relative shifts of an aircraft from an ideal approach path, upon an orthodox runway system, led to greater apparent angular changes in the pattern than the pilot would generally perceive. It was his belief that this accounted for the expression, which he had heard in various forms from many pilots who had experienced difficulty at night, that "the runway appeared to swing from side to side."

For those reasons he believed that reliance placed solely upon the perspective appearance of a visual aid pattern might be dangerous. As far as directional indication was concerned, the conclusion to be drawn was a simple one. Namely, that a pilot should not be asked to make a judgment of perspective convergence as a necessary part of the alignment of his aircraft. As the only alternative was to present him with two or more lights to be brought into geometrical alignment ahead, the centre line of lead-in lights proposed by Mr. Calvert followed as a logical conclusion, inescapable as the central part of a high intensity aid pattern.

Furthermore, to manœuvre an aircraft so as to bring the centre line lights into vertical alignment, it was necessary to have a horizontal datum. Parallel bars at right angles to the central line provided this datum, and had the great merit of possessing practically no perspective convergence. On this point it should be noted that the shorter the bars, the smaller would be the latter effect.

Mr. Calvert had suggested that the problem of making good the necessary glide path should be achieved by controlling the aircraft's descent so that each successive bar to pass out of view subtended the same angle to the pilot's eye, *i.e.* had the same apparent size. He himself was not happy about this, as apparent size depended upon the perspective pattern presented by the bar, and was undoubtedly subject to distortion, particu-

larly if structural qualities could be observed by the pilot in the individual light sources. To his mind the angles subtended by successive bars were an aid to the correct glide path, but not an entirely reliable one.

The vertical angles observed between close and distant light groups, so long as the latter did not fall into patterns of convergent lines, were free from perspective reduction, and should not be much affected by phenomenal regression. He would suggest, therefore, that the present pattern could be much improved by arranging the spacing of the bars, and of the individual units of the centre line, in a geometrical series from the point of origin. Any flight path, axial to the latter, would then present a pilot with a constant angular relationship in the vertical plane between each successive set of lights, as they assumed any given position.

The logical result of carrying this line of approach to its ultimate conclusion was undoubtedly to carry the centre line of the approach pattern on down the centre of the runway itself, using flush-type fittings, and to form a contact mat of short bars at right-angles to it, similar to the approach bars, but spaced at short intervals, providing a surface upon which the pilot landed his aircraft. He realised that there were great practical difficulties in putting such a system into effect.

In developing visual aid patterns, it must be remembered that human perception was achieved by a most complicated set of processes. The eye could only cover about 5° of the field presented to it at high visual acuity, *i.e.* using foveal vision, on a single fixation. While in motion from one fixation to another it was effectively blind. For accurate vision, according to experiments conducted in America, the eye usually averaged about four fixations per second. A visual pattern of wide angular extent, and presented for only a very short time, could not be covered in its entirety. Also, the judgment of the perspective angle between two widely spaced convergent lines was not made by a single fixation, but by a series, the result being an integration in the mind. To this extent, perspective diagrams should be treated with a certain amount of reserve. The importance of concentrating the light pattern into a narrow area under conditions of poor visibility, when any section of it was only visible for a very short time, would be seen. For this reason he felt that Mr. Calvert's bar pattern should be kept down to the narrowest reasonable angle, consistent with other requirements. The $2\frac{1}{2}°$ layout now installed at Farnborough appeared to be quite wide enough and any increase in the bar length would probably provide additional distraction, requiring a greater number of fixation points, without providing any further useful indication.

As a practising airline pilot, he would like to express the purely personal conviction that the provision of high intensity aid patterns, for use in conditions of poor visibility, would provide a great source of psychological reassurance in the latter stages of an instrument let-down. Many of them had learned through practical experience not to place undue reliance upon radio aids, particularly at remote bases in foreign countries. The general adoption of high intensity approach patterns, of the type proposed by Mr. Calvert, should prove an important safety factor, and it would be most encouraging to see Great Britain setting a lead to the world along those lines.

Although employed by a national airline, the views he had expressed were entirely his own.

Air Vice-Marshal Sir Conrad Collier (*Assoc. Fellow*): Mr. Calvert's work, with its careful and broad scientific approach, made a great impression on one who had a long background of the old type of night flying and night approach and landing. The problem was being approached from the modern standpoint of the long, straight approach, having in mind safety considerations, particularly in conditions of low visibility—all those things which had seemed not to have been possible under the old system of night flying.

He was reminded of the analogy of driving a car at night on a lighted London road in a bad fog; although the overhead lighting was quite good, when the fog was low all sense of lateral direction would be lost and turns either to right or left could be made unknowingly. Again, when considering Mr. Calvert's statement about the confusion arising from trying to follow a row of lights in the approach at night, he was reminded of what used to be called straight and level bombing, when there was no horizon and when bomb sights were unstabilised; the aircraft dropped a wing, and the bomb aimer corrected in yaw, thinking the pilot had turned off the target. That seemed to prove the principles which Mr. Calvert had put forward.

When trying the simulator at Farnborough, he had felt, although out of practice in the making of night landings, that it seemed to have possibilities as a trainer if properly developed, but people with far more experience in modern training had disagreed with him. He would like to hear views on the extent to which the simulator might be developed for training purposes, either in taxi-ing or in the approach.

N. E. Rowe (British European Airways, *Fellow*): For some time there had been controversy, which he believed continued, as to the ultimate aim in low visibility approaches and landings, whether the operations should be entirely automatic or whether they should end in a visual landing. He felt sure they should aim for the latter, as he believed that the fully-automatic approach and landing was still a long way off. He believed that the high intensity lighting in the patterns illustrated carried them a big step forward in achieving visual landing in conditions of low visibility.

He was a great believer in the principle of putting all they could on the ground, in the effort towards securing safety and regularity in all conditions of weather and visibility, which was essential if air transport were to be made a real means of transport and not just a fine weather service. Mr. Calvert had indicated how that could be done; but he would like to know its cost, how it compared with the cost of other aids, such as G.C.A. and radio and radar, and also whether there was ever a risk, for instance, of a complete failure of power.

The important thing Mr. Calvert had done was to put forward a completely logical and commonsense approach to the problem, which Mr. Majendie had shown to have great scientific backing. The simple idea of the cross bar seemed to be one of the finest conceptions in making landing easier, particularly under conditions of low visibility and probably fatigue, and that was the essence of attaining true safety.

The paper had also placed great emphasis on the need for a proper view from the cockpit; the lighting system described depended on an adequate view and an adequate angle of view over the runway, and the author had made a strong plea to designers. That view should be provided without any question at all, together with clarity of vision through the windscreen.

The problem of taxi-ing had the strongest bearing on the utilisation of airports, since it might be that the rate at which they could get aircraft down, and hence the maximum utilisation of major airports, would depend more directly on the rate at which they could get aircraft off the runways than on any other factor. Hence, good taxi-ing facilities and illumination in poor weather were of fundamental importance.

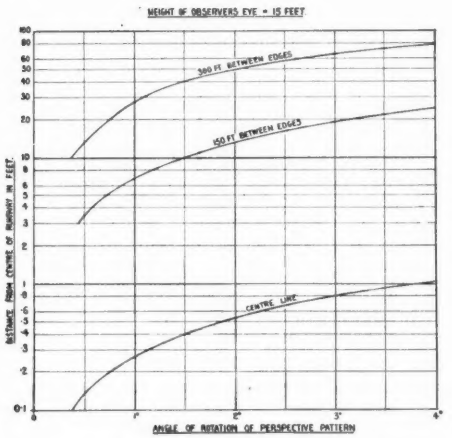
J. W. Sparks (Royal Aircraft Establishment): The paper should stimulate many people into thinking about the whys and wherefores of visual aids instead of taking them for granted.

He agreed strongly with Mr. Rowe about the importance of visual aids; further, he was quite sure that, for many years to come, most of the information a pilot used in order to manœuvre his aircraft from some point before he landed until the aircraft finally came to rest would be obtained by observation through the windscreen. If that were so, then everything the pilot saw might be regarded as a potential visual aid; and, as the author had said, it might be well worth while studying everything, *i.e.* the whole airport layout, from that angle as opposed to considering an airport in plan, which he believed had happened in the past.

Using methods such as were recommended by the author, for example, to examine the runway itself as a visual aid led to quite interesting and possibly surprising results. Under poor day-time visibility conditions a pilot who had landed his aircraft on a runway and was running along it, had to judge his lateral position by the pattern formed by the edges, if the runway had no texture and no day markings, because he had no aiming point, and the only features within his field of view which he could use were the edges of the runway.

The graphs showed how the pattern which the pilot saw—which was the edge of the runway—swung round because of lateral displacement. Also, the angles were quite small, the maximum shown being 4°. If they imagined that a pilot had landed his aircraft on the centre line and that the aircraft, instead of proceeding on a straight line, described an arc of large radius, as aircraft were inclined to do, because of various causes, it would continue on that arc until the pilot noticed that something was wrong. He would notice that something was wrong by the rotation of the pattern. The exact amount

by which he would deviate before he noticed that something was wrong was a variable quantity. But, assuming he noticed it when the pattern had rotated 3°, the graph showed that on a 300 ft. track he was at 70 ft., and on a 150 ft. track he was only 20 ft. off the centre line. Assuming he corrected there and proceeded on a curve in the other direction at the same radius, his maximum deviation from the centre would be twice his error at


HEIGHT OF OBSERVERS EYE = 15 FEET
300 FT BETWEEN EDGES
150 FT BETWEEN EDGES
CENTRE LINE
DISTANCE FROM CENTRE OF RUNWAY IN FEET
ANGLE OF ROTATION OF PERSPECTIVE PATTERN

the point where he corrected. With the wide track this was 140 ft. off, and with the narrow track 40 ft. off.

This confirmed that something was needed down the centre of a wide runway. He strongly suspected that on a wide track, with no centre line marking, pilots would tend to run their aircraft along one side, *i.e.* they would mis-use the runway. He urged that, given adequate marking, runways could be used to better advantage; a pilot could taxi faster with the aid of a centre line than with just edge markings.

J. M. Waldram (General Electric Co., Ltd.): As an illuminating engineer, but not a pilot or a psychologist, he was specially interested in the paper because it had fallen to his lot, and that of his colleagues, to tackle some similar problems of visibility during the war. He welcomed especially the use of the perspective method; he was convinced that it was the right way, and perhaps the only way, in which to tackle those problems—not from the subjective point of view, but from that of studying what was presented to the observer. He could point to a number of problems which had been solved by the perspective method and which he believed could only have been solved in that way. Such matters as phenomenal regression had their importance subjectively, but after it had been decided what to present to the pilot. In America recently he had noted that those studying the problem were making extensive use of perspective projections of their approach paths, on beautifully printed webs which bore acknowledgment to Mr. Calvert.

Mr. Calvert had emphasised the essential importance of avoiding field trials until they knew what they were doing. It had been found in similar problems during the war that field trials became quite unmanageable; they were out of control in the sense that important factors could not be controlled or even measured. The opinions of pilots and air observers were also proverbially erratic; it had been said that if twelve pilots were questioned thirteen different answers would be received, for one of them would change his mind! This implied no slur on pilots; most people would be similarly uncertain if asked, say, *exactly* what they did when riding a bicycle, or any similar task which they had not specially studied.

A full-scale experiment was to be distinguished from a demonstration; in an experiment the result was unknown and the experiment was designed to find it; whereas in a demonstration the result was known and the demonstration was designed to show it. The distinction was not always appreciated; and he and others had found that large full-scale experiments were attractive to administrative officers who had urgent decisions to make. It was almost inevitable that they formed conclusions on what they saw, without the opportunity to appreciate the limitations and implications of the experiment. If full-scale experiments had to be made, he felt that administrators should not be present, but should be invited at a later stage when the facts had been established and the project had reached the point of being demonstrated, when definite proposals could be put forward.

The simulator, in one form or another, seemed to be the right way of tackling the experimental side of these problems; and he hoped that Mr. Calvert would find another opportunity of describing in more detail the system which he and his colleagues had devised. He had seen similar experiments in America, and in his opinion they had

nothing to compare with Mr. Calvert's ingenious arrangement.

There were two factors which ruled the problem of bad-weather approach lighting. The first was "visibility"—a term which called for strict definition and usage. The meteorologists had a strict definition, but in practice the word was used loosely and in a variety of senses. It was important to recognise the potent effect of a small change of the meteorological visibility range. Any proposed layout of lights should be explored to find the effect of a small change of visibility, because sometimes such a change might turn a practicable scheme into one which was hopelessly impracticable. Mr. Calvert had wisely used this approach. When a system had been installed, somebody would have the operational responsibility of deciding the conditions in which it could not be used safely; and this introduced the need to find a way of measuring from the ground the visibility along an inclined line of sight from air to ground. This was not easy, for measurements made in the ground layer were sometimes most misleading as guides to what the pilot could see.

The second ruling factor was the pilot's view. The practicability of a pattern of lights turned upon assumptions made of the limitations of the pilot's view, and some of the differences of opinion of various authorities could be traced to this cause. For example, one writer had assumed a pilot's view typical of certain existing aircraft in which the pilot could not see the right hand side of the runway and could see the centre line only to a limited extent; therefore he advocated either a central line of lights or one on the left hand side only. Another authority was unconcerned with the limitations of present-day aircraft, on the argument that if in certain aircraft the pilot could not see, that type would be grounded in weather in which other aircraft, with a better view, could fly; and the builders would soon rectify the trouble; therefore he advocated a system which depended on the simultaneous view of lights at both sides of the runway.

It appeared from the geometry that the pilot's view was a most important factor which demanded the attention of designers. In a "funnel" in which there were two converging rows of lights was there a risk of misinterpreting either altitude or attitude in conditions in which the funnel only was visible and not the parallel runway lights?

The author had referred to a wide white touch-down area at the beginning of a runway; some work had been done by the Road Research Laboratory on the marking of pedestrian crossings, a geometrically similar problem. It had indicated the advantage of painting a crossing in broad bands, alternately black and white, parallel to the length of the road which, when seen from normal eye-height from a distance, appeared as a conspicuous dotted line across the road. The idea might be valuable for touch-down areas, and if it were it would provide an interesting example of the relationship between two research problems in very different fields.

Group Captain G. Silyn Roberts (Royal Aircraft Establishment, *Fellow*): Flying in conditions where there was no visual contact with the earth was no longer a problem over 300 ft. above the ground, but the problem of getting down again in conditions of bad visibility was not yet satisfactorily solved. There were radar and radio devices by means of which a pilot could descend comfortably and reasonably accurately to between 3 and 500 ft. above a selected point. The problem of landing after that was substantially overcome if it were possible to devise equipment in close contact with the ground which the pilot could see from about 500 ft. and which was so disposed that he could sense accurately his position and altitude in relation to the ground. He believed that the Calvert lighting system stood a good chance of enabling such visual contact with the ground to be made in conditions where the visibility was of the order of 300 yards.

He thought that Mr. Calvert's method of approach to the problem of analysing what the pilot's senses appreciated in manœuvring and approaching the ground for a landing was basically correct. Mr. Calvert's interpretation of the analysis would also appear to be the right one because tests made on the simulator by numerous pilots of varying experience had shown that there was no difficulty in making accurate approaches and arrivals on the runway using the Calvert pattern of approach lights. In the case of several, if not all, other existing systems even experienced pilots often found themselves in difficulties.

It would not be wise, he thought, to form any final opinion at this stage about the usefulness or limitations of the full-scale pattern because it had not been in existence long enough for sufficient experience to have

accumulated. Having used it, he thought that the basic shape and layout of the approach light pattern were quite satisfactory.

Opinions appeared to vary regarding the optimum intensity required, particularly at night. In daylight the intensity as it was would probably be judged to be satisfactory. At night, in good visibility, some pilots were of the opinion that the lights were too bright. They were certainly so intense that all the instruments in the cockpit disappeared unless the cockpit lighting was turned up to very nearly maximum brightness while flying through the approach light zone. Emerging from the brilliance of the Calvert system into the comparative darkness of the runway was rather disconcerting at first but the low intensity runway lights could be seen reasonably clearly.

Once having located the approach light systems the only instrument of vital importance was the air speed indicator. It should be possible to provide that instrument with adequate illumination. His own opinion was that one would soon get used to cockpit lighting adjusted to its maximum brightness.

The disconcerting darkness which occurred on leaving the approach lights just before touching down, would probably be eliminated by fitting higher intensity runway lights, but experience might prove that this feature was not hazardous.

He believed that landings, particularly at night, would be easier to make if runways were provided with centre line marking illuminated at night by flash lighting. Such an arrangement would enable the pilot to anticipate and correct any tendency to drift or swing much more easily and release some of his powers of concentration for the task of judging his height after levelling out. He believed that people's capabilities of concentration were very limited and that they became even more limited if there were a need to concentrate on two things at once. As an example, he recalled a single-engined aircraft which was noticeably unstable longitudinally and which had a disconcerting change of directional trim with change of speed and power. Fitting a contra-rotating propeller eliminated the variations of directional trim with speed and power, and although measurements indicated that the contra-rotating propeller had further destabilised the aircraft longitudinally, pilots were of the opinion that the aircraft was now perfectly satisfactory in every respect. The elimination of one undesirable feature requiring concentration had released so much ability to concentrate that the other undesirable feature had become unnoticeable.

He thought that trials were justified with the Calvert system modified so that the intensity could be varied to suit varying conditions of light, darkness and visibility, but the main thing to his mind was the natural ease with which a pilot was immediately conscious of his position and altitude in relation to the ground when the approach light pattern was in view. It was a matter of trials to arrive at the optimum intensity of illumination for varying atmospheric conditions.

He strongly supported the scheme for centre line taxi-ing lights. It was much easier to drive a car in the blackout on roads fitted with "cat's eyes" reflector centre lines than it was to ride a bicycle on present-day aerodromes complicated by illuminated taxi-tracks at night. The centre line system also lent itself to a precise traffic control system on the lines of the national railways.

Group Captain D. W. F. Bonham Carter (Ministry of Civil Aviation): During the war years he was in command of an R.A.F. bomber station. The aerodrome was equipped with the normal form of Airfield Lighting Mark II, which had been described in the paper. It had its limitations and he had evolved a system calling into use other lighting aids which were available to him and which had enabled him to achieve fair success in getting aircraft down rapidly under conditions of deteriorating visibility; 42 aircraft were landed in 31 minutes when visibility was 800 yards.

Nowadays they needed to go much further, and it was that consideration which had first impressed upon him the necessity for research on visual aids to landing under bad weather conditions. He believed Mr. Calvert was working on the right lines; experience would prove whether or not that was so, but he had fair confidence that he would be proved to have made a very real contribution to the solution of the problem. He was not sure, however, that when further experience was gained, Mr. Calvert's method of assessing height would prove to be the best, or the only, one that would be used by pilots when they were using his lighting. Pilots would use every available means of adding to the information which Mr. Calvert's system was aiming to give, so that they might be more

sure of their angle of approach during the descent.

The problem, as he saw it was, first to find the runway, second to get lined up with it, and finally to be at the beginning of the runway at the right time. It was that problem which the author had attempted to solve. But, having got on to the runway, an aircraft had to get off it, and the author's development of the system whereby he planned to provide a line down the middle was certainly necessary, because the bottle-neck might be that of getting aeroplanes off the runway and round the perimeter track in a limited time. There was also the problem of vehicles. Only recently, at the London Airport, an aeroplane was prevented from flying because it was impossible to guarantee that a stray vehicle had not wandered on to the runway. That problem had to be tackled.

Squadron Leader E. Coton (Royal Aircraft Establishment, *Assoc. Fellow*): In his experience the trouble with the pilot's psychology was that his ancestors had let him down very badly in neglecting to provide him with the instincts of an owl, or, in the matter of avoiding solid obstacles, the instincts of a bat; in the presence of lights the human pilot was like a moth. The double rows of lights on a runway made matters easier because they gave an equal pull on the pilot's attention to each side. But even in those circumstances, he had noticed that many pilots, having landed on an otherwise unlighted runway, would edge to the left, and finish the landing run in a series of lateral bounces off the left hand row of lights.

It would be a major tragedy if the proposal to light the centre lines of runways were dropped altogether because of the difficulties of installing it on runways that were already laid. If no centre line were visible at night, the time an aircraft spent on the runway was going to be substantially increased; the problem was to reduce that time, which was too great even in daylight at present. A possible way of achieving a reduction would be to re-design the taxiway lead-offs from the runway, making them more like arterial road forks than the back-street junctions they were at the moment. If that were done, then the centre line marking of the path which the aircraft had to follow was not merely desirable, but absolutely essential.

Mr. Calvert's work would not assist the over-burdened pilot in the blind approach to the lights. If it were to operate in the lowest possible visibility, the pilot must be sufficiently relieved that he could look out for the visual aid. This required the assistance of an automatic approach system, or of a co-pilot. The second alternative, he thought, would be best for civil use, and in the instrument stage the co-pilot should have control of the elevator, ailerons, rudder, and the trimmers. He would fly the beam in azimuth and keep constant air speed as required by the captain. The captain would control the descent through the power supply, and so keep the vital part of the control in his own hands. The co-pilot's job was purely mechanical—a non-pilot member of the crew could probably be trained to do it quite easily.

J. L. Russell (Ministry of Supply), *contributed*: The importance of the view from the cockpit had been mentioned. Mr. Calvert stated in his paper that in an aircraft with a downward view ahead of 15° below the horizon when the aircraft was flying level or 17° during an approach, then, in daylight, it should be possible to see six lights ahead when the meteorological visibility was about 200 yards. Mr. Calvert considered this to be about the lower limit of usefulness. He had made a few calculations on the basis that the system would work if it were possible to see six lights ahead and found that the limiting meteorological visibilities would be:—

180 yards for a downward view of 17°
230 yards for a downwards view of 12°
350 yards for a downward view of 7°

that was to say, an aircraft with a downward view of 17° would be able to make satisfactory landings in visibilities half as good as those required for an aircraft with a downward view of 7°.

Referring to the approach lighting system using flash discharge lamps mentioned by Mr. Calvert, it was claimed in *Aero Digest* dated August 1947 that these lights could be seen at a range of 1,000 ft. when the meteorological visibility was 50 ft. The same article stated that the brightness of the flash was 9 million candles per sq. in. which was about nine times that of the sun. The transmission factor for a fog in which the visibility was 50 ft. would be such that the apparent brightness of the krypton lamp would be reduced to that of the sun after the light had passed through 30 ft. of fog, so that if the light were burning continuously, it should be visible at a range 30 ft. greater than that of the sun.

In a uniform fog of such density, the sun would be visible through about 220 ft.

The claim that a flash of a few micro-seconds would be visible at a range of 1,000 ft. was clearly optimistic, to say the least.

The President: It seemed to him that the meeting had been discussing the problem of putting a symmetrical vehicle down on to a symmetrical runway, and he could not help feeling that certain difficulties of interpretation might be avoided if the pilot were on the centre line of the aircraft. Perhaps the effect was too small to bother about; but he would like to know whether or not that were the case.

MR. CALVERT'S REPLY

He thanked Sir Conrad Collier and all the other speakers who had said that the methods used by him and his colleagues were scientific. He was particularly gratified by Mr. Waldram's remarks on his use of perspective diagrams and the simulator, because Mr. Waldram was an expert in this kind of work, and had obtained valuable results by applying the same technique to street lighting.

Sir Conrad had raised the question of whether the simulator could be turned into a trainer. No doubt it could, but he thought that its immediate application was to demonstrate to fully-trained pilots how the various approach patterns behaved in fog. As explained in the paper, these patterns could behave in ways which were likely to disconcert a pilot the first time he tried to land on them in fog, but once their behaviour was understood and expected, the danger of an instinctive misinterpretation was removed, and the pilot's confidence was restored. A few runs on the simulator enabled a trained pilot to see exactly how any particular pattern behaved when he corrected various errors and, in the case of the bar pattern, to satisfy himself that there was no danger of his doing the wrong thing when only a small portion of the total pattern was seen. The R.A.E. simulator was not an expensive instrument and he hoped that one would be installed at every major British airport. The statement made by Sir Conrad that, in the absence of a horizon, a bomb-aimer corrected in yaw when the aircraft banked, was an excellent example of the ambiguity of ground indications in certain circumstances

Mr. Rowe had asked about cost. He thought that a system based on an angle of 3° would be satisfactory. The cost of such a system was not excessive and was certainly less than that of one air liner The cost, excluding that of the ground, might perhaps be somewhere in the region of £12,000 to £14,000 in an average case. As regards the risk of power failure, he believed that at London Airport everything possible had been done to avoid this. The circuits had been split up, two separate supplies had been brought in from the grid and a standby set had been installed.

Mr. Rowe, Group Captain Silyn Roberts, Group Captain Bonham Carter and Squadron Leader Coton were all agreed on the necessity for rapid taxi-ing. On wide taxiways, he could think of no solution for bad visibility except the centre line arrangement, but this necessitated the use of flush-type fittings. Satisfactory flush-type fittings were difficult to design, but he believed that the problem had been solved.

In the matter of field trials, he was in heartfelt agreement with Mr. Waldram. In the case of the visual aids, field trials cost an appalling amount of money, and were quite as likely to give a wrong answer as a right one, if indeed they could be said to give any answer at all. He disliked having administrators present at full-scale experiments for the same reasons as Mr. Waldram, but when urgent decisions had to be made, it was necessary that the technical people should take great pains to explain the situation to them at as early a stage as possible. The simulator had proved very valuable in this connection, because it had enabled a large number of administrators to grasp the elements of the problem in a short time. He estimated that he had given demonstrations to several hundred administrators.

Mr. Waldram had put his finger on a difficulty which they were now up against, namely, that of knowing when the slant transmission had fallen to such a low value that landings could not be made on the visual aids. His colleague, H. N. Green, had put forward a promising suggestion for solving this difficulty both by day and by night, and this would be tested next winter using a captive balloon. These tests would be part of a more general investigation of the transmission of light at various levels in various types of fog.

Mr. Waldram raised two other important points when he asked whether there was a risk, with the vee pattern, of misinterpreting

attitude and altitude. As regards attitude, the answer was that in bad visibility a system such as the plain vee, which did not include crossbars, confused attitude with lateral displacement. Such systems were dangerous, because if the pilot got the impression that he was laterally displaced when he was banked, he would put on more bank in order to correct this imaginary displacement, and might then spin into the ground, or strike it with his wing tip. As regards altitude, the answer was that pilots accustomed to landing on a pair of parallel lines, such as the Bartow system, would certainly misjudge their altitude if they tried to land on a vee in bad visibility, and *vice versa*. The reason for this was that the pilot of an aircraft coming down a path which intersected the runway at the apex of the vee, saw substantially the same series of pictures as the pilot of an aircraft flying level over a pair of parallel lines. This brought out very clearly the need for international standardisation.

Mr. Sparke had given an interesting demonstration of the difficulty of keeping straight on a wide track. He believed that the Americans had experienced this trouble in the Aleutians, where they had built runways 500 ft. wide. The conclusion seemed to be that wide runways, without suitable longitudinal markings, did not necessarily give increased safety, and that there might be no good reason for laying down concrete runways wider than 200 ft.

He agreed with Group Captain Silyn Roberts that there was discomfort glare from the Farnborough installation when run at full intensity on a clear night. For civil airports, probably the best way to prevent this was to install two sets of fittings, one set of low intensity, visible all round, for use at night, and the other set with directional beams for use in daytime and in very thick fog at night. For a given density of fog, the range obtained from a light of a given intensity at night was about the same as that obtained from a light 500 times brighter in daylight. It followed that if 100,000 candles represented about the highest intensity which it was practicable to use in the daytime, an equally good performance could be obtained at night with lights of a few hundred candles. As glare did not begin to be troublesome at night until the intensity exceeded about 1,000 candles, it followed that a better performance could be obtained from approach lights by night than by day. It should also be remembered that the Farnborough installation was incomplete in that the high intensity runway lights had not yet been installed, and landings had now to be made from high intensity approach lights into low intensity runway lights. He was about to start a series of tests to determine how many dimming stages were really needed. If low intensity fittings were used, he thought that one dimming stage on the low intensity, and one on the high intensity, would be sufficient. Possibly no dimming at all would be needed, the low intensity being used for almost all night conditions and the high intensity for daylight and dusk. After all, many of the fittings used in modern street lighting were several times brighter than those used in the Farnborough installation.

Group Captain Silyn Roberts, Squadron Leader Coton, Mr. Majendie and Mr. Sparke wanted the centre line of the approach system continued along the runway. This was the general opinion of all those who had made a systematic study of the problem, and he entirely agreed with them, particularly in view of the fact that the civil air liners of the future would probably all have nose-wheels. Unfortunately, a centre line was not thought of at the time when most runways were laid down, and to modify them now would be costly. The objections raised by some of the representatives of one of the airlines to the introduction of centre line taxiway lighting had convinced him that one must not bring up too many new ideas at one time. The crying need at the moment was for general agreement on approach lighting, and it would be time to consider detailed improvements if and when the horizon bar system had been generally adopted. Nevertheless, he thought that it would be a far-sighted act on the part of those responsible for the design of new airfields to provide a cable duct up the middle of all runways.

Mr. Russell had made two useful contributions, the first of which gave the facts as to the operational price which had to be paid for using aircraft with poor downward views. He would add that not only could the aircraft with the better view operate at a lower visibility, but that in any given visibility, the pilot's task would be easier, and the landings correspondingly safer.

Mr. Russell's demonstration that the krypton lamp, even if burning continuously, could not have a daylight range greater than 250 ft. in a meteorological visibility of 50 ft. was ingenious, and he believed it to be correct.

If it were true that these lights were observed at a slant range of 1,000 ft. when the visibility at ground level was 50 ft., then the explanation would appear to be that the fog was thicker near the ground. He had often observed this effect from his captive balloon.

He had left his comments on Mr. Majendie's contribution to the last, as some of the points raised were controversial and represented aspects of the problems on which he was not particularly qualified to speak. He was very glad to have this contribution, because there must be few practising airline pilots who had worked in a psychological laboratory, as he understood Mr. Majendie had done. He believed that he and Mr. Majendie were in substantial agreement, and his comments would therefore be brief, because he had a horror of being drawn into the verbal morass which was the bugbear of psychological discussions.

He thought the term "phenomenal regression," like many other psychological terms, was a rather cumbersome name for an effect of which many people were already aware. It seemed to him to be an effect which was present to a greater or less degree in all observations and that, as Mr. Waldram had pointed out, its existence did not in any way invalidate the use of the method of perspective analysis. It was obvious that if an observer were looking at a pattern, he would find it easier to interpret if the image on the retina of his eye were substantially the same shape as the pattern. In an approach system consisting of a pair of parallel lines, the retinal image was a truncated vee, and the pilot had to interpret this vee as meaning a pair of parallel lines, an act which became more difficult the less he saw of it, *i.e.* the worse the visibility. In the horizon bar system the retinal image was the shape of a herring bone, and so was the pattern itself, and this might well be one reason why pilots liked it.

He did not agree with Mr. Majendie that phenomenal regression explained why the runway sometimes appeared to swing from side to side. To accept phenomenal regression as the explanation implied different reduction factors for the perspective angles of each of two lines viewed simultaneously and he found himself unable to believe that this occurred. In science it was a general principle to prefer the simple explanation to the complicated one, and he therefore preferred the explanation which he had given in the paper and which Sir Conrad Collier had confirmed. On the other hand, phenomenal regression might explain momentary misjudgments of height. It certainly seemed to confirm the necessity for texture.

The idea of making the spaces between the bars increase in geometric progression with respect to the point of origin was one which he had seriously considered when laying out the Farnborough installation, but he had rejected it for a number of reasons.

(1) It would increase the number of lights in the vicinity of the runway threshold and would therefore increase glare at a critical stage of the landing.

(2) It would reduce the number of bars at the outer end of the approach system, which was where the pilot saw the smallest portion of the pattern, and had the greatest difficulty in interpreting it.

(3) It might upset judgments of speed. This was probably not important.

(4) Pilots were familiar with equal spacing on runways and might not like unequal spacings in the approach zone.

However, as Mr. Majendie thought that the advantages might outweigh the disadvantages, he proposed to try this pattern on the simulator and compare the approaches made on it by a number of observers with those made by the same observers on other forms of the bar pattern.

Mr. Majendie had observed the Farnborough installations during repeated landings in thin radiation fog, and he was interested to note that Mr. Majendie thought that an angle of $2\frac{1}{2}^\circ$ was sufficiently wide. He himself now thought that a system based on an angle of 3° with the origin 1,200 ft. from the threshold might be an improvement. He also proposed to increase the spacing between the lights in the bar, and also to fix it at a constant value for all bars. This would save fittings, and would reduce the glare in the vicinity of the runway.

He was surprised at the wide and sympathetic interest shown in the ideas put forward in the paper. Indeed, he thought that in the matter of criticism, he had been let off very lightly. Truth lay at the bottom of a well and the more controversy there was, the sooner it would be discovered. He doubted if he would ever have thought of the bar pattern if he had not been stimulated by the discussions which he had had at I.C.A.O. and with his opposite numbers in America.

THE ROYAL AERONAUTICAL SOCIETY

AIRCRAFT ACCIDENTS

CAN CHANCES OF SURVIVAL BE INCREASED?

by R. E. HARDINGHAM, O.B.E.

Secretary of the Air Registration Board.

INTRODUCTION.

I feel that it is now more necessary than ever before to present some unbiased views on the subject of aircraft accidents in general and of crash survival in particular. Discussion of the subject must surely be useful, although the outcome may not necessarily be wholly welcome to all sections of the Aircraft Industry.

For some time past members of the staff of the Air Registration Board have been considering the problem of how to increase the chances of survival of the occupants of an aeroplane in the regrettable event of a crash, and of how to reduce the degree of any injury which may take place. Before definite design requirements are justified or recommendations are of value, it is necessary to ascertain facts. To do this a large amount of crash research and analysis, on a scale not at present undertaken in this country, would be entailed and it is doubtful even if this would provide conclusive answers unless undertaken on an international basis. In the meantime it is possible to form certain tentative conclusions and, in presenting this paper, I hope to interest and stimulate the thoughts of those responsible for the design, construction and development of civil aircraft.

The reader of the daily newspapers is all too familiar with the pictures and headlines which invariably follow a major crash. Although there is justification in some cases for such notoriety to be decried as "one-sided" and "failing to present a true picture," such reports do perform a useful purpose if they serve to bring home to designers, operators and authorities, that there is still much room for improvement before they may be satisfied with the aeroplane as a vehicle of transport.

When, however, one tries to interest the members of a design organisation in providing safeguards against the event of a crash, there is often too little interest displayed and one hears such remarks as "I design my aeroplanes to fly, not to crash." Of course an aeroplane must be designed to fly, but to think of it as never crashing is unfortunately an illusion which sooner or later will cost passengers their lives.

It is necessary to dispel the illusion that present attempts to perfect the aeroplane as a flying machine justify lack of consideration of the crash case. It is a fact that in more than 90 per cent. of all accidents (including those which make such distressing headlines in the press) the cause is not lack of airworthiness but is of an operational nature, unexpected weather or error of judgment. Adequate confirmation of this is provided by the most recently published British and American figures. I do not make this point on behalf of a self-righteous airworthiness authority—because I do feel there is still much to be done in the way of design to reduce the strain on flight crew and the likelihood of errors— but to show that the vast majority of crashes are due to causes beyond the designer's control. It is a matter of statistics—which can be made to show almost anything and with which I will not trouble the reader—that accidents, although occurring less and less frequently in terms of passenger miles, do by any standard still occur in all too considerable numbers and, I fear, will continue to occur for some time to come.

The period before the war may perhaps be considered the pioneering stage of air transport which, since then, has developed prodigiously to its present state. It seems probable that we may now look forward to a period of consolidation when safety may have pride of place, and with the new aeroplanes designed for little greater range or speed than those contemplated to-day. It is my hope that the contents of this paper may help towards the saving of life in those 90 odd per cent. of accidents which cannot be averted by providing complete airworthiness.

ACCIDENTS.

I would have liked to have given a cut and dried analysis of the different types of accidents and their results. There is not, however, enough information on a sufficiently large

number of accidents and I apologise for the generalisations given in the following list of types of accidents. It is fair to point out that these generalisations are not wild guesses but are the considered opinions of persons who have undertaken much research on this subject.

TYPE A.

Well over 50 per cent. of all crashes are associated with take-off, landing or forced landing. In these comparatively low-speed crashes casualties vary from all occupants killed to none killed, but it is remarkable when analysed under headings of the different types of aeroplane, how some appear to kill the majority of their occupants while other types involved in comparable or more severe impacts kill none, or only the most forward occupants.

It is no exaggeration to say that all aircraft should be at least as good as the better ones in this respect and instead of the high percentage of occupants being killed in some modern air liners, over 90 per cent. should survive without serious injury.

TYPE B.

The next most frequent type of accident is that caused by flying into the ground when descending, or flying into rising ground at cruising speed.

Here again, there is evidence to show that this type of accident can be survived by at least a large proportion of the occupants.

TYPE C.

Not more than 10 per cent. of all crashes are associated with catastrophic impact such as occurs on flying into a vertical mountain face, or diving into the ground after structural failure or collision.

In this type of accident there is much less chance of survival than in the others.

TYPE D.

A small proportion of crashes are "ditchings." Here again, there is a very wide variation of survival as between different types of aeroplane, but a safe escape from the aeroplane should be 100 per cent. in reasonable water conditions, instead of the very low percentage which is so often the case.

TYPE E.

There are some miscellaneous crashes which cannot be grouped into the previous headings and which amount to about 10 per cent. of all crashes. No estimates can be given for these but it is perhaps reasonable to assume that 50 per cent. would be survivable.

It would appear to be a fair overall estimate that at least 70 per cent. of crashes of a severity which is 100 per cent. fatal with some types of modern air liner, are fundamentally survivable. Surely this is a challenge to the designer as great as those accidents (at most 10 per cent. of the total) which can be put down to imperfect airworthiness.

There are few statistics as to the cause of death in airline accidents, but there is little doubt that 70 per cent. to 80 per cent. of all fatalities are caused finally by burning. Of this total probably 20 per cent. to 30 per cent. would have escaped in time but for physical injury or having been trapped in the wreckage. Although drowning accounts for but a small proportion of the total victims, it is the cause of death of the majority of those killed as a result of ditching.

CAUSES OF DEATH AND DESIGN FOR SAFETY.

PHYSICAL INJURY.

The avoidance of actual physical injury to the occupants is obviously of prime importance, for if they cannot survive the initial impact there is no need to consider later developments.

The first consideration is stalling speed. If take-off and landing and forced landing crashes were to occur at lower speeds there would undoubtedly be less risk of injury. In one of my early flights I experienced no less than four forced landings between London and Newcastle with never a thought of danger; in some modern transport aeroplanes the chances are that in four forced landings I would be quite likely to be burnt to death twice.

Some interesting research undertaken in the United States shows that the most prevalent cause of fatality from mechanical causes is head injury and that this may be avoided by restraining the occupants from leaving their seats and arranging that there is nothing within their orbit of movement, when restrained, on which they might hit their heads. There is absolutely no doubt that the simplest way of providing this restraint is by the use of aft-facing seats giving support to the back and head. These provide almost complete protection within their strength at all times during flight and it follows that the greater the strength of the

seat, the greater is the impact that can be survived. Where to draw the line would appear to be more a matter of ethics than of engineering, but I see no reason to quibble with the A.P.970 figure of 25 "g". For accelerations of this order it is necessary to provide a heel board, or the feet may fly under the seat, thus causing severe leg injuries.

For forward-facing seats a safety belt of conventional form has been proved well able to give restraint of over 12 "g" without injuring its wearer, but to be useful it is essential for there to be no hard objects which the occupant's head will hit when moving in an arc about the restrained hips. In this respect careful attention must be paid to the design of the back of the seat immediately in front. Safety can be aided by leaving the seat backs free to pivot forward out of the way of the occupant of the seat behind. In any case, a passenger can increase his safety considerably in an anticipated crash by bending forward against the seat in front and so not being thrown there through an impact.

For pilots who have to sit close behind instruments and controls an improved chance of survival is gained by sinking all the instruments into a facia board of smooth sheet metal. Frangible control wheels, or wheels with knobs in the hub, should be avoided. Protection comparable to a backward-facing seat can be provided by a safety harness which can be made to give safe restraint without injury up to at least 40 "g".

Other points in cabin design to reduce injury are to use flush fittings whenever possible so as to avoid knobs and projections which, if the occupants are thrown against them, can be as lethal as pole-axes; to contain loose baggage and equipment so that it cannot hurtle down the cabin; and to provide adequate floor strength (preferably at a good distance above the belly skin) to minimise the risk of leg injury. Adequate structural strength should be provided in high wing designs to prevent complete crushing of the aircraft belly and consequent injury to the occupants, jamming exits, and so on.

TRAPPING.

The fact of being trapped in an aeroplane, although not fatal in itself, frequently leads to death by burning or drowning. Recent accident evidence suggests that the emergency exits required at present, although satisfactory in theory, are not used in a real emergency. In panic conditions, for instance, passengers seem to forget everything but the door through which they entered the aeroplane and for land crashes it is suggested that there should be at least one main door each side of the rear fuselage. This would give a chance of at least one door still being serviceable with the fuselage lying over to one side, as is frequently the case. It is also useful in the event of a fire starting on one side only as it may permit escape on the other side. For ditching, emergency exits should be provided giving access to the top of the rear fuselage and the top of the wings.

It should be borne in mind that passengers are not always of slender build and, when wearing a life-jacket, require a hole of reasonable dimensions if escape is to be rapid.

In all cases of exit location an intelligent appreciation should be made of an exit in such a position as a means of escape. It is no good (as has sometimes been done) to provide openings through which an occupant can only go head first to a 10 or 12 ft. drop to the ground without even a hand hold.

It may be noted that I mentioned exits in the rear fuselage; I would not discourage exits in the front as well, but it is essential to have good exits well to the rear where the risk of distortion is least.

Since the natural tendency is to use the doors, it is essential that exits should be clearly marked and as simple in operation as ordinary doors.

FIRE.

Fire is the greatest killer and so long as aeroplanes have to be constructed largely of massive hot engines with exhausts like blowlamps and with tanks full of highly inflammable fluid, it will remain one of the hardest risks to subjugate. The position is not hopeless, for not all aeroplanes turn themselves into bonfires in a mishap with such almost unfailing regularity as do some of the large passenger aeroplanes in use to-day.

The two fundamental precautions in preventing fire are to contain the inflammable fluids and to minimise the chances of ignition.

There are three main methods of containing fuel; these are sheet metal tanks, integral tanks and bag tanks. In the event of any structural distortion, such as is likely to occur in a crash, it is probable that an integral tank

will be ruptured, whereas a bag tank may be undamaged in similar circumstances. For this reason, although I can as yet produce no numerical proof, I am convinced that bag tanks are much safer than integral tanks. It is difficult to assess the risk of plain sheet metal tanks, but this probably depends to a considerable extent on the nature and position of their installation.

It is most important to mount tanks where they will not be likely to be damaged or, if damaged, to spill their contents over a source of ignition. This would appear to lead to the conclusion that high wing tanks are safer than low wing tanks and that tanks should certainly not be so located that they will be ruptured by undercarriage collapse.

Tank sumps, pumps, collector boxes and fuel lines should be mounted within strong parts of the structure and not in excrescences underneath the aeroplane where they are likely to be ripped off. Shut-off cocks, similarly, should be mounted on strong structure rather than where they will be torn off in the event of an engine breaking away on impact.

Sources of ignition most likely to start a fire are the engines and the electrical system. Again, I cannot provide quantitative proof, but it seems that a very real measure of protection can be given by automatic crash switches which actuate fire extinguishing systems to cool the engine and entirely blanket it in a cloud of extinguishant. Although it is my firm conviction that crash-operated fire extinguishers can provide most valuable protection, they are only likely to do so if a real attempt is made to appreciate the service they can perform and to relate the characteristics and installation and the means of crash operation to the hazards inherent in the particular aeroplane design. Much work remains to be done on the question of how much the crash switch should do, whether, for example, it should shut down the engines, and on the question of what sensitivity of operation is desirable. An equally important function of the crash switch is to isolate the batteries from all heavy duty circuits and from as much other wiring as possible. Anyone who has seen a high discharge battery shorted to the aircraft structure through low resistance wiring, such as a generator feed line, will realise what á potent source of ignition this provides.

There seems to be no doubt that a change to kerosene fuel will be beneficial as, in many cases, it is the high volatility of petrol which promotes its ignition. Also, a kerosene fire spreads less rapidly and gives rather more chance of escape.

On the subject of giving time for escape it is worth mentioning that the farther the fuel is from the fuselage, the better, and that petrol tanks should never be included in a low wing centre section in the fuselage. In numerous crashes of aircraft with this type of construction it has been shown that the occupants have little chance of escape if the tanks rupture into the fuselage and fire then occurs. Fuel tanks should be as far outboard as possible, but they should not be so far out as to render them likely to be ruptured in a one-wheel or sideslip landing.

WATER.

Drowning occurs in far too many ditchings. The all-important thing is sufficiently good ditching qualities to make it possible to put an aeroplane down without it breaking up. Model tests are of real value in this connection and a low wing is almost essential for a landplane. The next most important thing is for the aeroplane to float; if it floats well enough for the occupants to be able to stay aboard until rescued, there is a very good chance of survival, but the aeroplane should in any event float long enough for the occupants to be able to board dinghies without panic. The Skymaster which ditched in the Pacific provides an example of how survival is possible if the aeroplane will ditch and float. It is not difficult to imagine what would have happened in the incident if the aeroplane had only lasted the minutes which are quite usual for a landplane.

The automatic release of dinghies has not been notably satisfactory in the past but this is a matter of detail design which should not be difficult to remedy.

CONCLUSION.

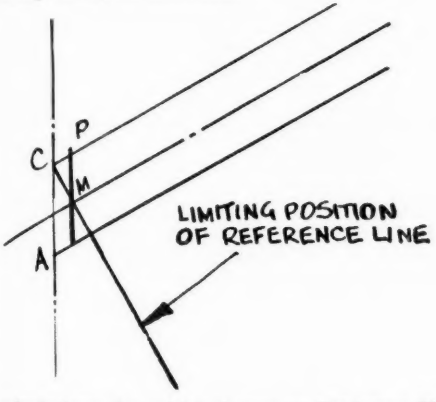
In conclusion I would like to express the hope that, both nationally and internationally, it may be possible to undertake more research into the avoidance of crash injury and death. I feel, also, that it is most important that design organisations should be supplied with the fullest possible information on all crashes. Although the causes of accidents may be beyond their control the information would, I am sure, enable them to go far towards mitigating the present horrible results.

Correspondence will be welcomed on the points raised in this paper.

CORRESPONDENCE

DISTORTION OF SWEPT-BACK WINGS

Professor G. T. R. Hill's paper on "The Nature of the Distortion of Swept-Back Wings" (p. 186, March 1948 JOURNAL) contains in para. 6 some conclusions which, I think, are erroneous. If the definition of zero twist as given in Fig. 5 is applied to the example shown in Fig. 7 it will be seen that the locus of flexural centres for the case considered (*i.e.* ribs along wind) is incorrect.



Consider the case in which the reference line is at its limiting position, that is intersecting the rear spar at the centre line of the aircraft. Since point *C* is considered fixed then for the reference line to have zero twist the front spar must of necessity be undeflected.

For this condition to be satisfied point *P* must lie on the rear spar. The locus of the flexural centres cannot therefore intersect the rear spar at the centre line of the aircraft for the rib configuration considered.

The locus of flexural centres shown in Fig. 7 does however show a marked resemblance to that appropriate to a different case, ribs normal to the spars; calculations for which I sent to Professor Hill in November 1946.

The analysis is as follows:—

Assumptions:

For the purposes of simplified treatment consider two spars of constant values of I in which the front and rear spars are of equal flexural rigidity.

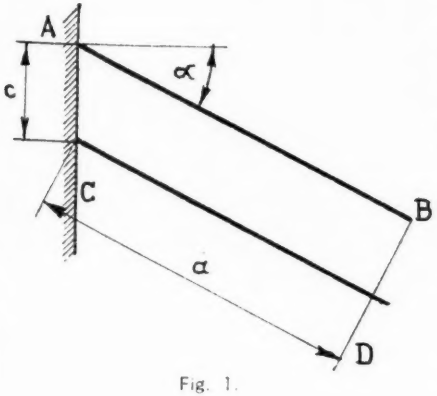


Fig. 1.

The front and rear spars are connected by a rib *BD*. *BD* is normal to the spars and is considered unable to transmit moments either parallel to, or normal to, the planes of the spars. It is only able to transmit shear reactions. Both spars are considered rigidly encastred at their roots.

Treatment:

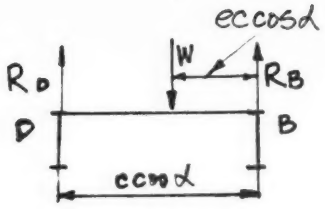
Imagine a load W applied at B.
Then deflection of front spar at B.

$$\delta_F = [W(a + c\sin\alpha)^3]/(K) \quad . \quad (1)$$

Now imagine a load W applied at D.
Then deflection of rear spar at D.

$$\delta_R = (Wa^3)/(K) \quad . \quad . \quad . \quad (2)$$

If the load W is now moved to a position defined by the parameter e (along the rib) we have



$$R_D = We \quad . \quad . \quad . \quad (3)$$

$$R_B = W(1-e) \quad . \quad . \quad (4)$$

$$\therefore \quad \delta F_e = [W(1-e)(a + c\sin)^3]/K \quad . \quad (5)$$

(Deflection at front spar with load positioned by e.)

Similarly we have

$$\delta R_e = (Wea^3)/(K) \quad . \quad . \quad . \quad (6)$$

Thus position of flexural axis is given by:

$$[W(1-e)(a + c\sin\alpha)^3]/K = (Wea^3)/K$$

or

$$(1-e)/(e) = a^3/(a + c\sin\alpha)^3 \quad . \quad (8)$$

$q = \frac{(a)}{(c\sin\alpha)}$	.25	.50	1	2	3	4	5	6	7	8	9	10
$e =$	.992	.964	.889	.771	.703	.661	.663	.614	.599	.587	.578	.571

It will be noted that the result is equally true for a rib rigidly attached to front and rear spars and able to transmit moments in its own plane but not in planes parallel to the spars.

The treatment is of course of very limited use since the boundary conditions at the root, in practice, are not likely even to approximate to those assumed.

Albert Rose, B.Sc., D.I.C., A.F.R.Ae.S.

PROFESSOR HILL'S REPLY

I am most grateful to Mr. Rose for pointing out a mistake which has crept into Fig. 7 in my recent paper on "The Nature of the Distortion of Swept-back Wings." With the assumptions I have made, the locus should intersect the rear spar a little way out from the centre line.

Looking at the matter again in the light of Mr. Rose's correction, it seems to me that perhaps the choice of reference line as defined in Fig. 5 is not a very fortunate one. This reference line was chosen as explained in the text purely on the score of simplicity in calculation. It seems clear now that it would have been better to have accepted the slight additional labour of making the calculation with a reference line passing through P instead of M. This would give a picture very like Fig. 7, in fact on the scale of a drawing, it would probably be hardly distinguishable from it.

As Mr. Rose says, it is quite true that if the ribs had been supposed mounted at right angles to the spars instead of along wind, a result very similar to that shown in Fig. 7 would obtain, and I feel it would throw additional light on the whole subject if Mr. Rose could publish in the JOURNAL the result of calculations he sent to me some time ago. Although the structures chosen are obviously over-simplified, I feel that the result which he has established, that the inclusion of the torsional stiffness of the spars does not affect the position of the locus, is a point of importance in that it indicates that the general shape and position of this locus is not affected to any major degree by a considerably closer approach to reality in the representation of the wing structure.

G. T. R. Hill, M.Sc., M.I.Mech.E., F.R.Ae.S.

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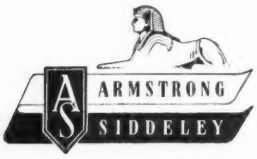

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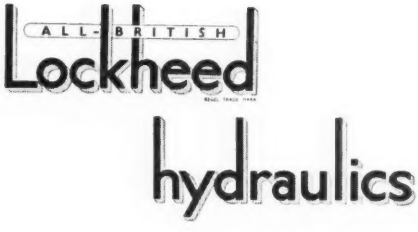

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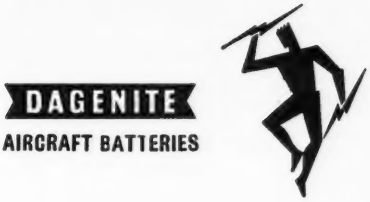

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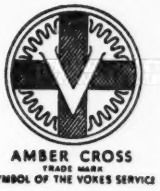

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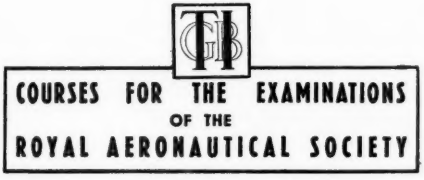

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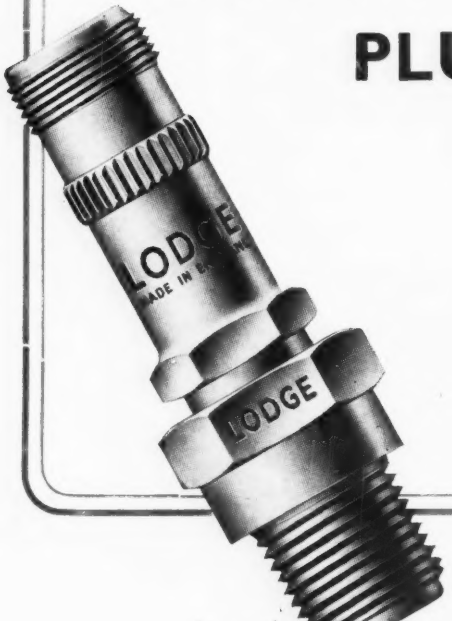

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